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SEISMOGRAPH EVIDENCE ON THE DEPTH OF THE SALT IN SOUTHERN MISSISSIPPI*

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ABSTRACT

Reflection seismograph records shot over the tops of shallow salt domes in Southern Mississippi show deep events which can reasonably be identified as reflections from the base of the salt. Calculations reveal the depth to the bottom of the salt mass to be approximately 22,000 to 26,000 feet.

A number of shallow salt domes in Southern Mississippi have been surveyed by means of the seismograph. Reflection records, shot and recorded directly over the tops of several of these domes, exhibit persistent deep reflections which are believed to come from the base of the source bed of salt. The data from these records permit a fairly accurate calculation of the depth to the bottom of the salt.

Fig. 1 shows two sample seismograph records, together with a diagrammatic sketch, illustrating the type of recordings which have been observed. A distinctive feature of the records is the long time interval, following shortly after the shot moment, in which no evidence of reflections appears in the background of random noise. This portion of the records is assumed to represent the time required by the seismic wave to travel vertically down and back through the relatively uniform salt mass of the dome. Immediately following this reflection-free interval is seen a good reflected event which apparently comes from a deep interface that is probably associated with the base of the salt. It appears reasonable to identify this interface with the contact between the salt and the subjacent sediments, for it may be expected that this contact is the best reflecting surface in the lower portion of the stratigraphic section. The self-consistent results obtained by plot-

* Presented at the annual meeting, Denver, Colorado, April, 1942.

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ting such reflections recorded from a series of shots over a single dome lends credence to this hypothesis. Reflections from still deeper underlying sedimentary strata can also be seen; and on one of the records shallow reflections from cap rock are clearly in evidence.

For computing depths from the observed time data speeds of 14,800 and 7400 feet per second were used in the salt and overlying sediments respectively. The depth so calculated to the base of the salt in Dome "A" is 25,800 feet while for Dome "B" it is 22,400 feet. The cap rock on Dome "A" gives a good reflection at a depth of 2400 feet but the reflection from the much shallower cap rock of Dome "B" is obscured by the high noise level on the early part of the record. These two domes are located in the south central part of Mississippi in the general neighborhood of the Choctaw Base Line.

An examination of many records of the type reproduced in Fig. 1 shows that the salt-sediment interface is not always a good reflecting surface, for the amplitude and character of the reflection are quite variable. This might be taken to indicate that between the salt and the sediments there may exist either an intermediate transition zone of lithological gradation or a ragged interface caused by infolding of salt and sediments. At any rate, the resultant effect is to render the absolute depth determinations somewhat uncertain, although it is believed that a fairly reliable direct measure of the depth to the lower boundary of the salt has been obtained.

The seismograph shooting on which the above conclusions are based was carried out at the suggestion of various members of the geophysical staff of the Gulf Research & Development Company. The author served merely to compile the results.

AN ANALYSIS OF ABNORMAL REFLEXIONS*

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ABSTRACT

During the course of a reflexion survey of an area in Southwest Texas, a group of seismograms was obtained on which were recorded a number of events having abnormal apparent velocities. The dips computed from these events on the assumption that they were conventional reflexions in the plane of the profile were much larger than the anticipated stratigraphic dip. This paper presents a discussion of the possible origins of these events and an analysis which affords considerable evidence that they originated on fault planes.

Wave fronts having abnormal apparent velocities were observed on portions of most profiles shot in a certain area of Southwest Texas. Fig. 1 shows the relative positions of the shot points and datum lines

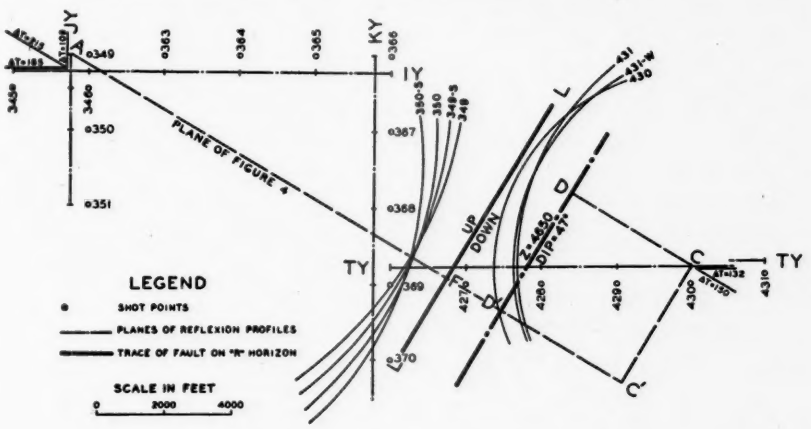

FIG. 1. Location of profiles and fault traces.

in a part of the area and Fig. 2 is a reproduction of typical seismograms displaying events of the character under review. The field technique employed was that of continuous profiles comprising individual spreads of 2250 feet span with detectors spaced at intervals of 150 feet; shot points were offset 1000 feet at right angles to the ends of each spread.

The abnormal wave fronts if interpreted as reflexions from stratigraphic beds resulted in computed dips much larger than would be

* Read by Mr. Frank Goldstone at the Denver meeting, April, 1942.

† Shell Oil Company, Inc., Houston, Texas.

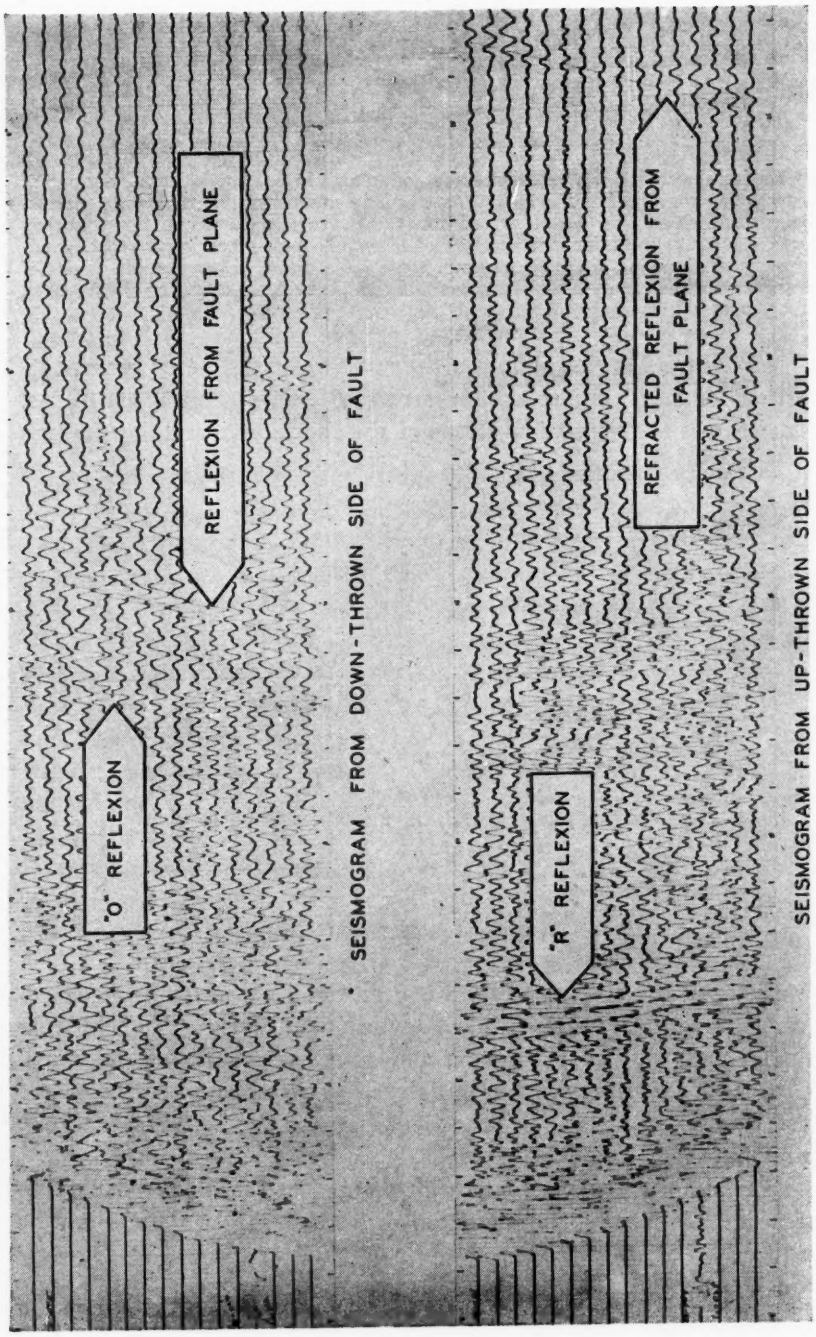
"O" REFLEXION
REFLEXION FROM FAULT PLANE
SEISMOGRAM FROM DOWN-THROWN SIDE OF FAULT
"R" REFLEXION
REFRACTED REFLEXION FROM FAULT PLANE
SEISMOGRAM FROM UP-THROWN SIDE OF FAULT

FIG. 2. Seismograms illustrating typical abnormal reflexions.

expected from the known geology of the area and entirely at variance with other seismic data. Since these abnormal wave fronts could not be attributed to reflexions from steeply dipping stratigraphic horizons, a preliminary analysis was made to determine whether they were near-surface waves reflected from escarpments, creeks, or other natural or artificial embankments. The loci of possible surface features which satisfy the observed data are, as a first approximation, the circular arcs shown on Fig. 1. The center of each arc is the midpoint of a line from the shot point to the detector, and the radius of each arc is obtained by multiplying one half the total travel time by 8250 feet per second, the approximate velocity of the first consolidated layer. The common tangent to each group of arcs gives the approximate position of the reflecting plane if located at the surface of the ground. No visible surface escarpment or artificial embankment was found at this position. The strike of the common tangent to the arcs, however, approximately parallels the strike of faults predicted from other seismic data. This strongly indicated that the abnormal wave fronts were actually reflexions from fault planes and suggested that a more detailed analysis of the data should be made.

A quantitative investigation of the possible fault plane reflexions is greatly facilitated if we first construct a chart showing systems of trajectories and lines of equal elapsed time. The only velocity information available in this area was the T—normal ΔT data computed from the continuous profiles. An empirical equation relating depth and terminal velocity of the form $V=7900+.6Z$ checked these experimental data within 1% from a depth of 5000 feet to 11,000 feet, and within 4% from 2000 feet to 5000 feet. This empirical equation was used to compute the trajectory and wave front diagram presented as Fig. 3. The lines of equal elapsed time are for the half trajectory, and the differential time values on each trajectory are for a spread span of 2250 feet.

If the magnitude and direction of the maximum ΔT are known and if the total travel time is known, then the position in space from which the reflexion occurs can be determined graphically from the wave-front diagram. For example, the maximum ΔT at the intersection of IY and JY of Fig. 1 and half the total running time of the reflexion at shot point 349 were observed to be .215 and 1.434 seconds, respectively. Using these values and the wave front diagram, the trajectory is found to be AEB (Fig. 4), with the dip of the reflecting plane being given by the tangent, IH, to the wave front at B. A similar analysis

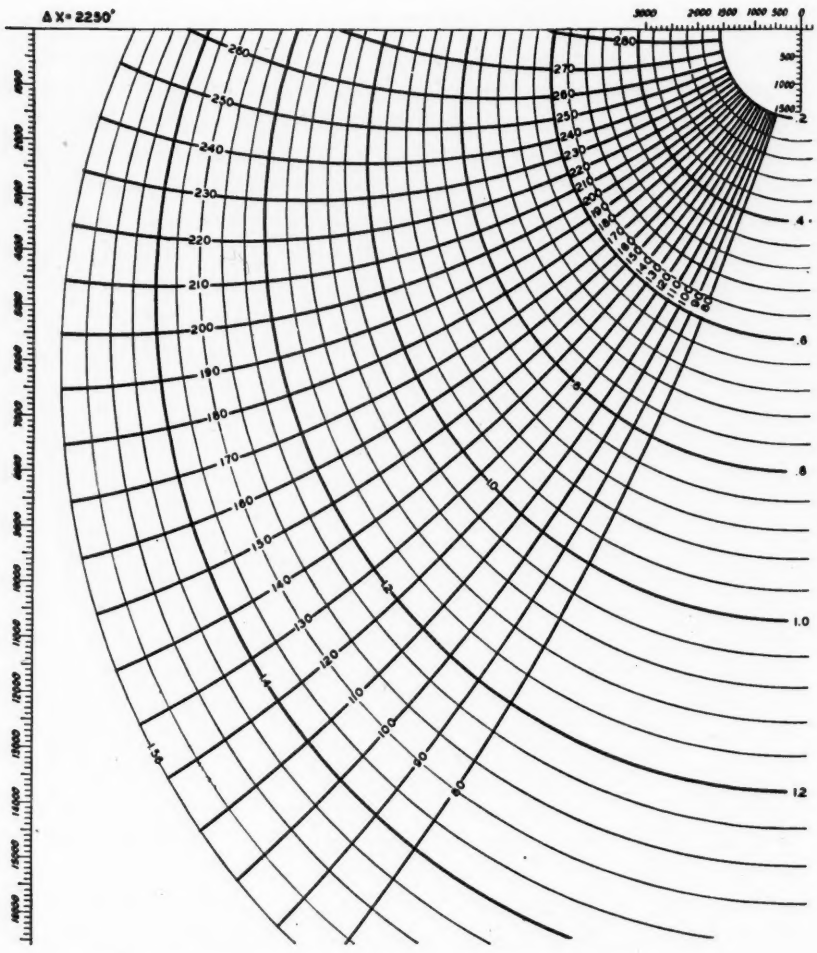

FIG. 3. Portion of a trajectory — wave front chart constructed for $x = 2250'$ and $V = 7900 + 0.6Z$.

of abnormal reflexion times at the intersection of other profiles in the same area also gave maximum ΔT's approximately equal to .215 second and suggested vertical reflecting planes similar to IH. Since the plane IH does not coincide with any determined fault in the area and since vertical fault planes would not be expected to exist, the trajectory paths such as AEB are considered to be highly improbable.

Another possible path of the abnormal reflexion at the intersection of IY and JY is the trajectory given by AEG on Fig. 4. The computa-

tion of this path is a matter of trial and error, since the depth Z of the horizontal path EF is unknown and since the position G from which the reflexion occurs is unknown. Three assumptions were made in computing the path AEG: (1) that the strike of the fault from which the reflexion occurs is given by the normal to the direction of maximum ΔT; (2) that the reflexion came from a fault plane previously determined by correlation reflexion data on profile TY (Figs. 1 and 5); and (3) that the point of reflexion G occurs in near coincidence with

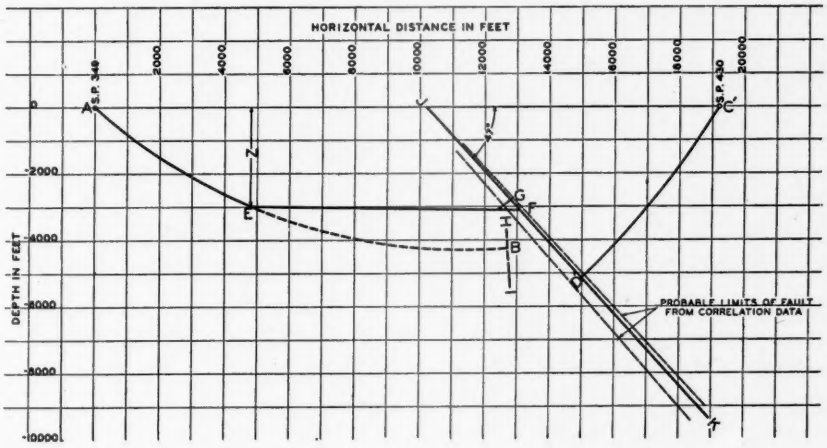

FIG. 4. Diagram showing possible trajectories of abnormal reflexions from shot points 349 and 430 resolved onto a common vertical plane.

the intersection of the horizontal path EF and the fault plane or, more probably, that the reflexion actually takes place at F, the reflected energy remaining in the layer below EF. The position of the fault plane JK is determined from the first two assumptions. The horizontal velocity of 10,500 feet per second for the horizon EF is determined by the ratio of the spread span, 2250 feet, to the maximum ΔT, .215 second. On the above assumptions the depth Z was found to be 2990 feet. It is interesting to note that the depth of the horizon EF thus determined is only 80 feet deeper than the computed depth of the "R" reflexion (Figs. 2 and 5), an event whose amplitude is approximately ten times that of other reflexions in this area. This tends to substantiate the above analysis ascribing the abnormal reflexions on the upthrown side of the fault to refracted waves traversing the path AEF, since the "R" horizon which furnishes such excellent reflexions

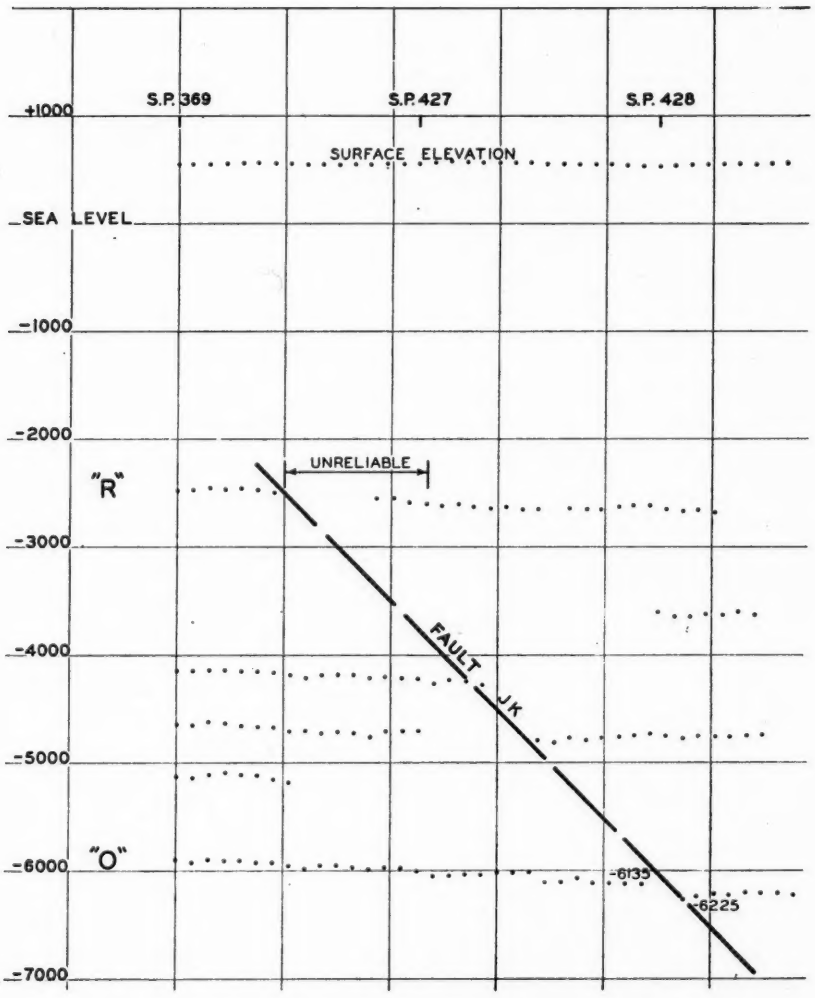

FIG. 5. Reflexion profile *TY* showing correlation evidence for fault *JK*.

is likely to focus considerable refracted energy. Further supporting this theory of reflected refractions is the observation that where the "*R*" reflexion is missing or weak, the above type of abnormal reflexion is either not clearly defined or not recognizable.

At shot points 430 and 431 on profile *TY* an abnormal reflexion was observed on which the component ΔT was .132 second. A transverse component was not observed so that the direction of maximum ΔT is

unknown; for the purposes of the present speculation it was assumed to be normal to the line *LL* (see Fig. 1). The resultant maximum ΔT computed from this assumption is .150 second. This value seemed to be too low for this wave front to be of the type analyzed above and it was suggested that it might be occasioned by a direct reflexion from the fault plane *LL*. Using a ΔT of .150 second and half the total travel time, .715 second, the computed trajectory from the wave front diagram is the line *CD* of Fig. 4. The reflecting surface given by the tangent to the wave front at *D* is the plane *JK* which is in experimental agreement with the fault determined from vertical reflexion data on profile *TY*.

Fig. 4 presents a summary of the evidence. The position of the fault plane *JK* as determined from abnormal reflexions on the upthrown and downthrown sides is shown to be within the limits previously determined by correlation reflexion shooting. Many other similar examples of such reflexions occur in this same general area although, as far as the author is aware, very few have been observed elsewhere. An interesting comparison is afforded by the observations of C. A. Swartz and P. W. Lindsey.[1]

The author wishes to acknowledge his indebtedness to Dr. W. Hafner and Mr. T. S. Edrington for valuable suggestions, to Mr. O. G. Holekamp for aid in computation, and to Shell Oil Company, Inc., for permission to publish this paper.

DISCUSSION

We have observed this kind of effect on several occasions both in California and in the Mid-Continent area. Although the entire record referred to in Fig. 2 as "seismogram from down thrown side of fault" cannot be seen completely, it appears that there is at least a suggestion of a reflection following "reflection from fault plane" about 0.130 seconds later and parallel with the "fault" reflection.

If this second event is verified by inspection of the record, then either secondary shot disturbance or a reflected refraction involving two types of waves is required. The two types of waves might be both compressional from two different fault planes, or they might be compressional and shear waves from the same fault plane. The shear waves to be expected are those generated by the refraction process. The separation of the two reflections would then depend on the Poisson ratio and the length of path in the material traversed by both compressional and shear waves. Reference might well be made in this instance to the tables included in the paper of Muskat and Meres (GEOPHYSICS, Vol. V, pp. 115–148, 1940) to get a rough idea of the relative amplitudes to be expected.

HEWITT DIX
United Geophysical Company

[1] *Reflected Refractions.* GEOPHYSICS, Vol. VII, No. 1, pp. 78–81 (Jan., 1942).

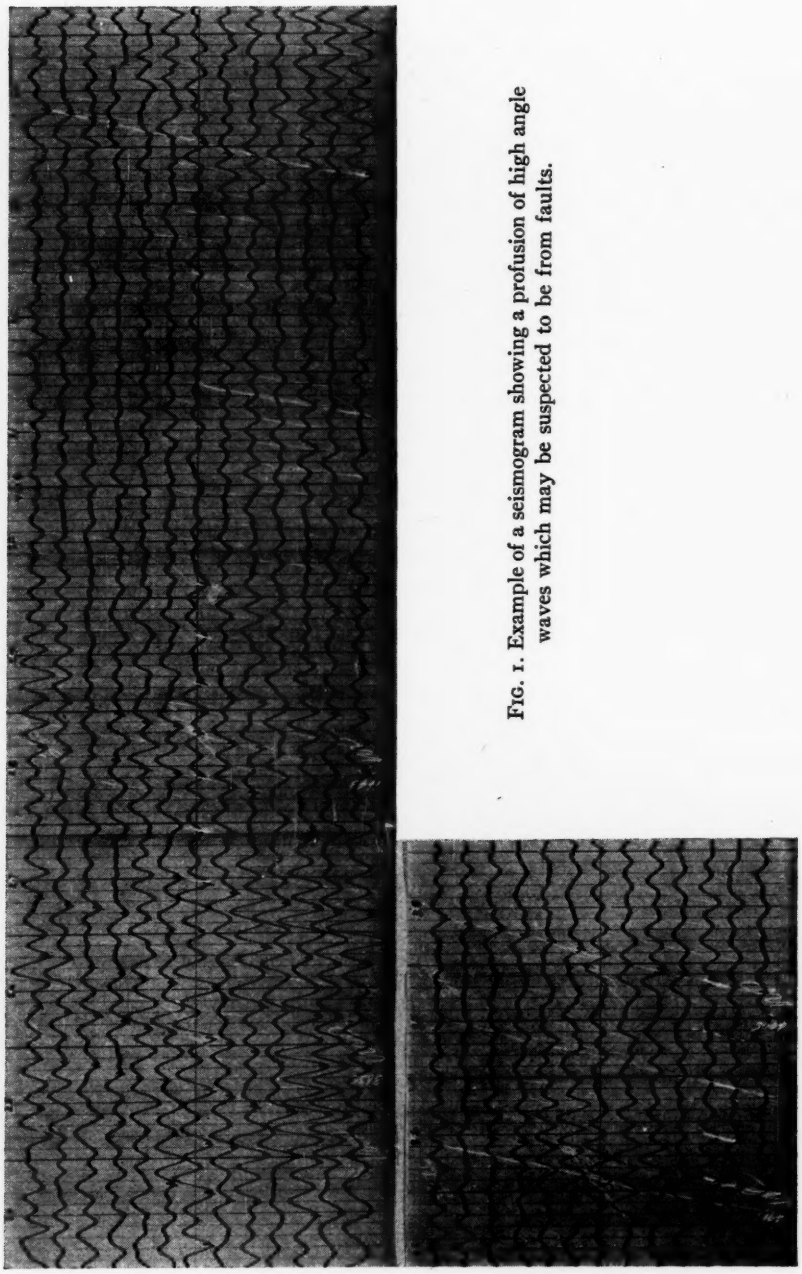

FIG. 1. Example of a seismogram showing a profusion of high angle waves which may be suspected to be from faults.

Mr. Deacon's paper seems to me to be an example of the type of computational research which will become more common and more in demand as the reflection seismograph is called upon to solve more and more complicated structural and stratigraphic problems. Probably most of us in reflection seismograph work have noticed and have plotted by *routine* methods, abnormal wave fronts appearing on our records such as those illustrated in Mr. Deacon's paper. Unfortunately it is seldom that individual study is given to such "reflections" and still more seldom that such individual study is published. Mr. Deacon has collected a rather convincing set of data from which to draw conclusions, although a California operator would wish for more information regarding velocity.

This paper brings to mind my paper published some time ago dealing with reflections from fault planes in California.[1] For that paper no such careful detailed analysis as is found in Mr. Deacon's paper was attempted; instead, several illustrations were given showing the quantity of fault reflections obtained in certain areas with the Rieber Sonograph. At the present time, I wish my paper *had* contained analyses of the type given here by Mr. Deacon, but I am convinced that in spite of the relatively primitive computation methods used for the purposes of my paper there can be little doubt but that Rieber obtained an enormous number of fault reflections, a large number of which were correctly interpreted as being from faults. Had a computational technique similar to Mr. Deacon's been employed, no doubt the locations of the faults described in my paper would have been more accurate, particularly in the cases of reflections or refracted reflections from the under side of the fault.

Unlike the area of Mr. Deacon's paper, most areas worked by the reflection seismograph in California have not been noted for their few outstanding correlating beds of high velocity contrast to the beds above or below. Thus California investigators generally have less to guide them in determining by "cut-and-try" the most probable reflection-refraction path for suspicious waves having large "move-outs." This difficulty has no doubt discouraged such investigations in California and will probably continue to do so. Moreover, in most parts of California, reflections from bedding and (suspected) from faults alike occur in considerable profusion, thus rendering interpretation laborious.

As an example of a profusion of high angle waves which may be suspected to be from faults, a portion of a seismogram is reproduced herewith in Fig. 6. This particular record is reproduced by courtesy of the General Petroleum Corporation, but anyone who has extensively seismographed the south half of the San Joaquin Valley or the Los Angeles Basin will probably recall having seen such records in his own files. The geophone spread was 400 feet and the average moveout 0.060 sec. On a cross shot with a 400 foot spread the average moveout was about 0.020 sec. For horizontal arrival these moveouts would indicate a velocity of 6320 feet per second, which is just about the observed horizontal velocity immediately below the weathered layer. The weathered layer was about 43 feet thick and the weathered velocity about 2000 feet per second.

Extensive regional seismographing indicates moderate dips over the entire area from which the observed high angle waves might have been reflected. No surface evidence of faulting exists as far as I am aware anywhere near the possible area of reflection. No direct correlation evidence of faulting is conclusive in the area, which like many

[1] Johnson, C. H. *Locating and detailing fault formations by means of the Geo-Sonograph.* GEOPHYSICS, Vol. III, No. 3, pp. 273–291 (July, 1938).

or most California areas yields poor correlations. And, finally, the continuing repetition of the observed high angle arrivals from about 1.8 seconds to nearly 4.0 seconds suggests some form of multiple reflections and/or refractions rather than a series of simple reflections.

This illustration is given in the hope that readers may be induced to suggest solutions or additional measurements to take in the area to contribute to a solution of the problem.

To stimulate imagination, and, perhaps, constructive controversy, one particularly interesting solution for which the data here given is necessary and sufficient, is described below. It was first suggested to me by Reed C. Lawlor, now with Consolidated Engineering Corporation, at the time when we were both employed by Rieber Laboratory and when records similar to the present illustration were obtained by Rieber in the same area.

This explanation assumes horizontal travel in the 6320 feet per second layer, and makes use of the uniform time interval between successive wave arrivals. It may be noted that in parts of the record, a new arrival apparently occurs every alternate wavelength. For example, there are deep troughs (separated by shallow troughs) at times of: 2.378, 2.424, 2.468, 2.515 . . . 2.920 and 2.968 for an average interval of .0454 second, and other similar sequences may be found.

At 2000 feet per second 0.0454 second represents very nearly the time for one round trip through the weathered layer at the critical angle. Thus Lawlor's theory begins to emerge:

Suppose there exists at a time of 0.9 second, in the proper direction from the point of observation, a more or less vertical discontinuity in the sub-weathered layer. (Nine-tenths second was chosen because the first observable large moveout wave occurs at 1.8 seconds.) A wave travelling from the shot in the sub-weathered layer to the discontinuity will be reflected and retrace its path to the vicinity of the shot point where it will be refracted upward through the weathered layer to the geophone spread. This would give a single large moveout wave.

However, Lawlor points out, under the proper conditions many other paths exist along which waves may be propagated with relatively little loss of energy to reach the geophone spread after refraction from the 6320 feet per second layer at a succession of later times. In our example, the principal assumption we must make is that the time through the weathered layer at the critical angle remains essentially constant between the shot-geophone location and the location of the postulated vertical discontinuity. If this condition be satisfied, there are an infinite number of identical time paths differing from that described in the preceding paragraph by the inclusion of a different round-trip "side excursion" through the weathered layer at the critical angle somewhere between shot and reception. The energy loss due to refraction is largely offset by the integrations of the energy travelling over the "infinite" identical-time paths. Such a wave, with a single weathered layer side trip, would appear roughly .045 second after the first reflected-refracted wave described.

Similarly the addition of two, three, four and more side trips through the weathered layer yields a series of nearly identical large moveout waves such as are observed in the illustration.

According to the theory, the total number of times that such reflections can appear on a record after refraction from a single interface and reflection at the surface, depends on the horizontal distance from the shot point to the discontinuity and the horizontal ditance traveled by a wave in a single side trip through the weathered layer.

In the area in which Mr. Deacon obtained his record, the theory predicts that a second reflected refraction may occur on Mr. Deacon's seismogram at a time 1.28 seconds later than the first reflected refraction observed. This "side excursion" time of 1.28 seconds is twice the time required for the wave to travel from the shot point to the refracting layer along the path *AE*.

In the present instance this wave would be too weak to observe, since the horizontal distance from the shot point *A* to the reflecting point *F*, is just large enough to permit a single side trip from the top of the bed *EF*, to the surface, and return. However, if the shotpoint *A* were at a greater distance from the reflecting point *F*, the intensity of this second refracted reflection would be greater due to the integration effect described above, and probably observable if the bed *EF* is parallel to the surface *AJ*. In this area, the detection of an additional reflected refraction becomes possible for each increase in horizontal distance from *A* to *F* of 9600 feet (that is, twice the horizontal distance from *A* to *E*).

It should be remarked that it is unnecessary, and probably incorrect, to assume that the energy travelling horizontally from *E* to *F* is entirely reflected within bed *EF*. Due to the angle of the fault face, such a reflection would be expected to return differential energies from *F* to *E* considerably out of phase, if, indeed, any measurable energy at all were returned along such a path. This difficulty is largely overcome if consideration is given to the energy refracted upward from bed *EF* as the wave travels from *E* to *F*, reflected from the fault face in the medium above bed *EF*, refracted into bed *EF* again, and thereafter propagated toward *E* in bed *EF*. It will be noted that in the case illustrated by Mr. Deacon, the wave front of the refracted energy in the medium above *EF* is almost parallel to the fault face. Thus energy reflected from a considerable area of the fault face will be in phase after re-entering bed *EF* to produce a strong reflected refraction as observed.

Similarly any reflected refractions occurring on the down dip side of the fault would be very weak because the fault face is nearly perpendicular to any similar refracted wave it reflects.

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A RESISTIVITY SURVEY OF THE MONUMENT OIL FIELD*

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ABSTRACT

This paper describes an electrical resistivity survey made in 1935 of an area in New Mexico now known as the Monument Field. From the data obtained a map showing the structure at the base of the Red Beds was prepared which is in good agreement with structure disclosed by wells later drilled.

INTRODUCTION

This paper describes a direct current electrical survey of the Monument structure in Townships 19 and 20 South, Ranges 36 and 37 East, Southeastern New Mexico. This survey is thought to be of considerable interest because the resistivity data obtained can be directly interpreted in terms of subsurface structural conditions. The work herein described was done in the spring and summer of 1935 by a Geophysical Research Corporation party under the supervision of the late Ernest Blondeau.

A log of a well in the center of the Monument Field is shown in Fig. 1. The section consists of a very thin surface cap, a comparatively thick section of sand and shale (Red Beds), and a massive layer of anhydrite and salt underlain by a thick lime section. Production is obtained from a porous zone in the lime approximately 4000 feet below the surface.

Judging from the geological conditions in the previously developed Hobbs Field, and from other geological evidence, there was every reason to believe that the structure at the base of the Red Beds would conform with the structure on the lime horizon so that a structure map showing the base of the Red Beds would be an indication of structure on the lime. The resistivity survey was therefore designed to map the conformation of the contact at the base of the Red Beds.

The Red Bed section is a relatively good conductor of electricity while the anhydrite-salt section is a very poor conductor. The ratio of the conductivities is sufficiently great for the anhydrite-salt section to be considered a perfect insulator compared with the Red Beds. The cap rock, on the surface, is sufficiently thin, compared with the thickness of the Red Beds, so that its effect may be neglected. From the

* Presented at the Annual Meeting, Denver, Colorado, April 24, 1942.

† Geophysical Research Corporation, Tulsa, Oklahoma.

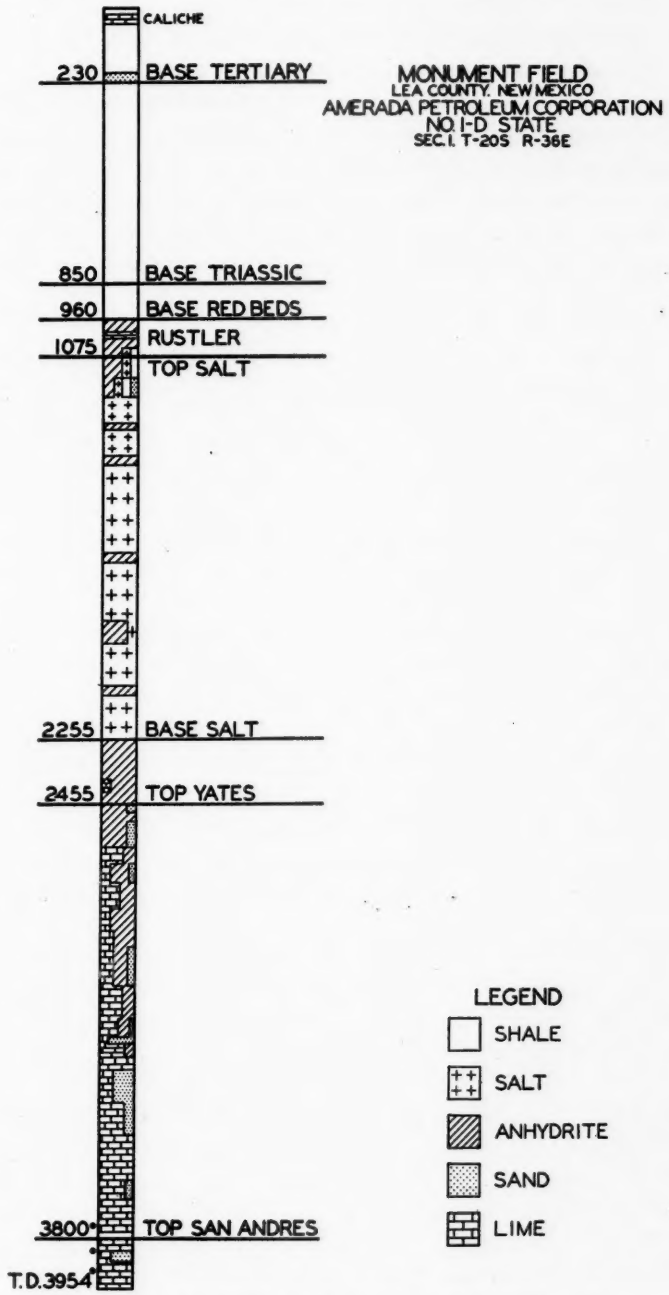

FIG. 1. Log of the Amerada No. 1-D Well, Monument Field.

standpoint of an electrical resistivity survey, therefore, the geological section closely approaches a conducting section extending from the surface to the base of the Red Beds, with a perfect insulator beneath. This fact makes possible the use of a very simple formula in computing the depth to the base of the Red Beds from the resistivity data obtained. Furthermore, the top of the insulating layer lies approximately 1000 feet below the surface, a depth to which current penetration can be obtained with a moderate distance between current electrodes.

FIELD TECHNIQUE AND METHODS OF COMPUTATION

A four-electrode system was employed with current electrodes spaced 6000 feet apart. A fixed potential electrode was placed midway

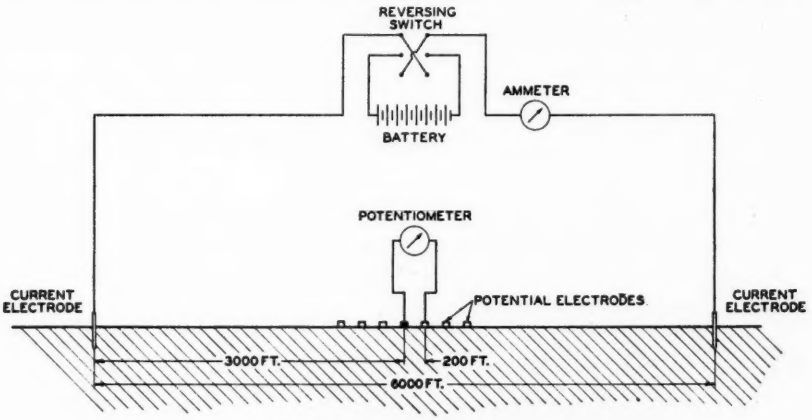

FIG. 2. Schematic diagram showing arrangement of current and potential electrodes.

between the current electrodes, and movable potential electrode was placed successively at points 200, 400, and 600 feet on either side of the central potential electrode. The arrangement of the current and potential electrodes is illustrated in Fig. 2.

Exciting current was obtained from a bank of storage batteries. Each current electrode consisted of a number of iron stakes driven into the ground. The earth surrounding the current electrodes was soaked with a salt solution to insure good contact.

The potential electrodes used were of the porous pot non-polarizing type employing a solution of copper sulphate in contact with a copper rod. The exciting current was read with an ammeter and the potential

differences between the movable and center electrodes were read by means of a potentiometer. To eliminate the effect of natural earth currents, the potential differences and the exciting current were first measured with the exciting current flowing in one direction, and the measurements immediately repeated with the current reversed. The mean of several such pairs of observations is free from effects due to natural earth potentials.

To translate the observed data into determinations of depth to the insulating layer, the formula for current flow in an infinite conducting plate was used, namely

$$E/I = (1/2\pi kd) \log r_2/r_1 \qquad (1)$$

where E is the potential at a point on the surface of the plate located at distances r_1 and r_2 from the two current electrodes, I is the total current through the plate, k is the specific conductivity of the plate, and d is its thickness.

It may be noted that the right-hand side of Eq. 1 is zero when the point considered is at the center of the spread. Consequently, the potential difference measured between the central potential electrode and a potential electrode at a point removed therefrom may be substituted for the quantity E in Eq. 1, and the value of the product kd can then be computed. If a value for the conductivity k is known or assumed, the thickness d may also be computed.

As previously stated, a total of six potential differences was observed at each setup, three on either side of the center of the spread. The value of the product kd was computed from each of these observations and an average of the six values thus obtained was taken to represent the value of the product kd applicable to a point beneath the center of the spread.

From data obtained in electrical surveys previously conducted, the conductivity of the Red Beds was estimated to be approximately 0.031 reciprocal ohm feet. As a first approximation, the depth d was therefore computed by substituting this value for k in the product kd computed from Eq. 1.

Five lines of profiles were run, a depth determination being made at intervals of 6000 feet along the line of each profile. Fig. 3 is a map showing the location of each station. The computed depth to the base of the Red Beds, corrected to sea level datum, is plotted at each station, and contours drawn using a contour interval of 100 feet.

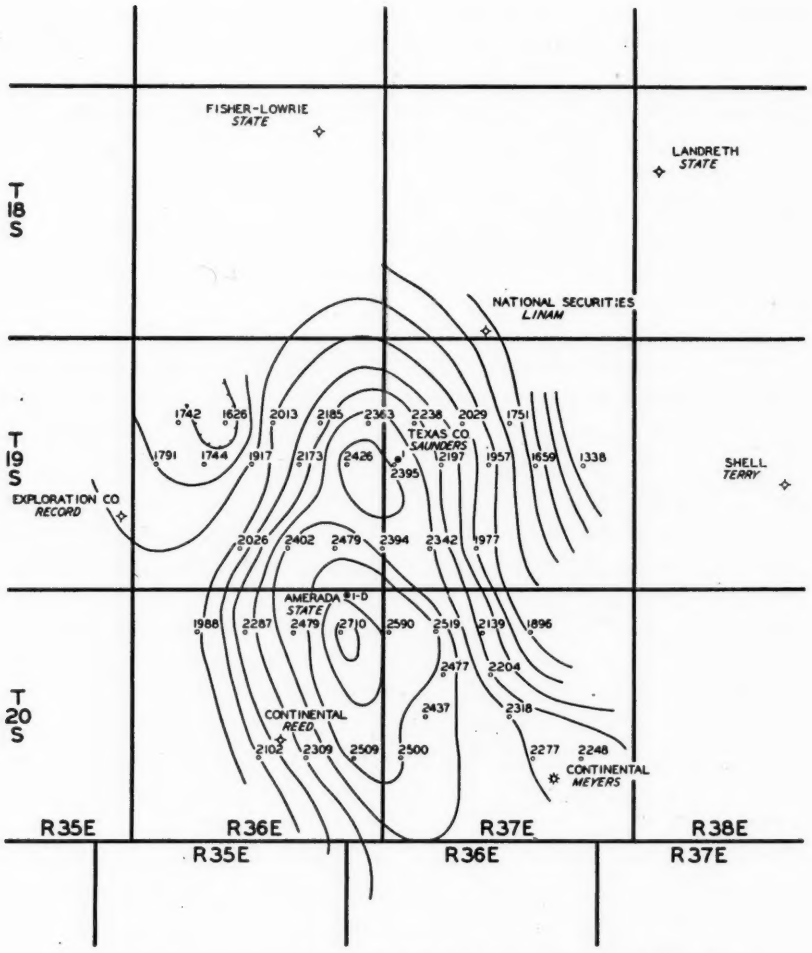

FIG. 3. Contour map on base of Red Beds. From resistivity data, using conductivity of .031 reciprocal ohm feet. Contour interval 100 feet.

During the course of resistivity surveys in this general area, it became evident that there were considerable lateral changes in the conductivity of the Red Bed section. It was therefore apparent that a more nearly correct structural picture could be obtained from the resistivity data by making a correction to allow for this variation of conductivity. Accordingly, a simple method of making such correction was devised. The logs of nine previously drilled wells were used to obtain data for this purpose. A resistivity profile was laid out across each

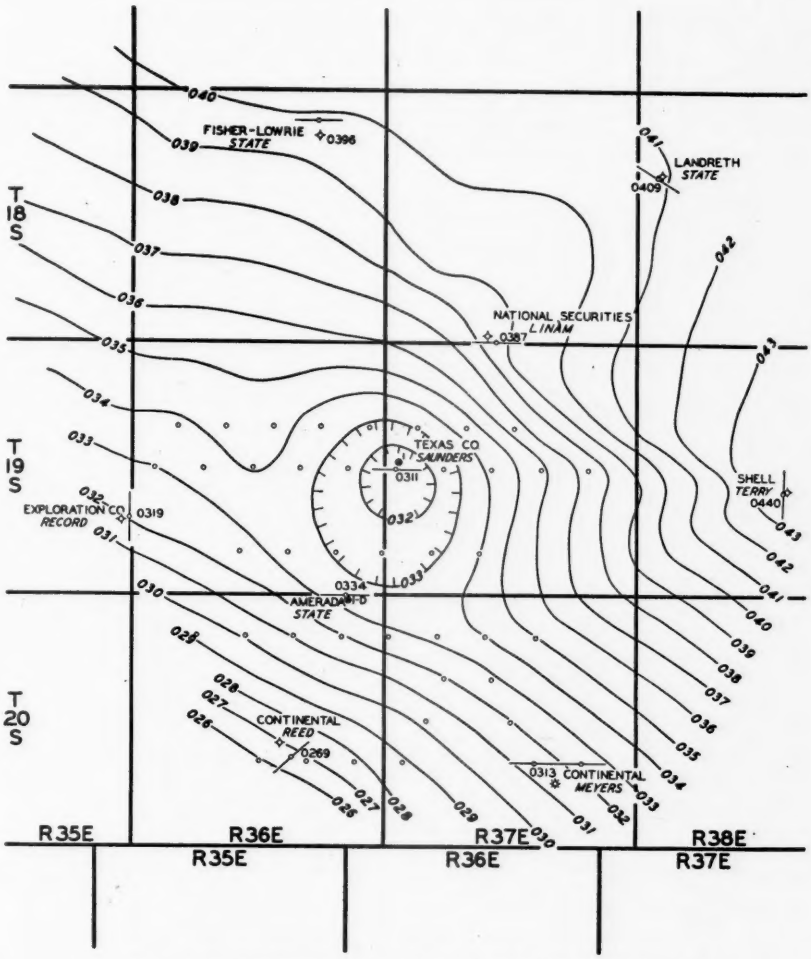

FIG. 4. Iso-conductivity map. From data taken across wells shown. Contour interval .01 reciprocal ohm feet.

of these wells. Since the depth to the base of the Red Beds was known from the log of the well, the value of the conductivity of the Red Beds in the vicinity of each well could be computed by means of Eq. 1. An iso-conductivity map of the area in question was then prepared. This map is shown in Fig. 4. It may be noted that the conductivity varies from .0269 to .040 reciprocal ohm feet.

The resistivity data taken over the Monument structure were then recomputed. Instead of using the conductivity value .031 at all loca-

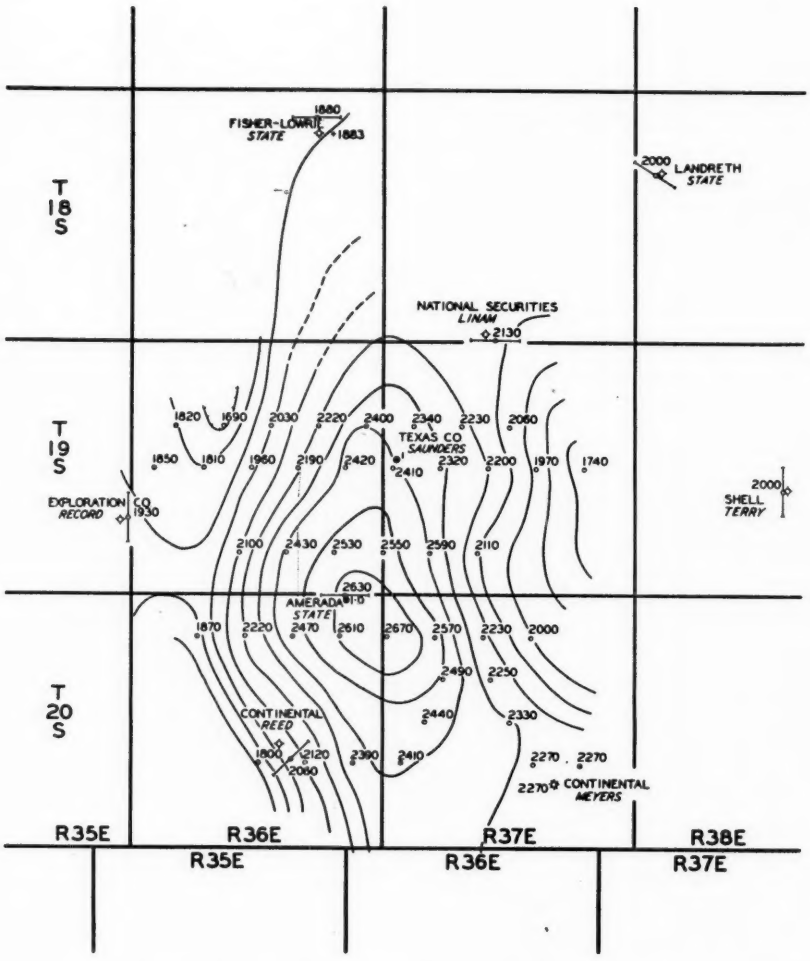

FIG. 5. Contour map on base of Red Beds. From resistivity data, corrected for lateral changes in conductivity. Contour interval 100 feet.

tions, the appropriate value at each location was estimated from the iso-conductivity map of Fig. 4 and used to compute a corrected depth. A contour map, made from data so corrected, is shown in Fig. 5. For comparison, a subsurface map later made from logs of wells in the Monument Field is shown in Fig. 6. The agreement between the two is quite striking.

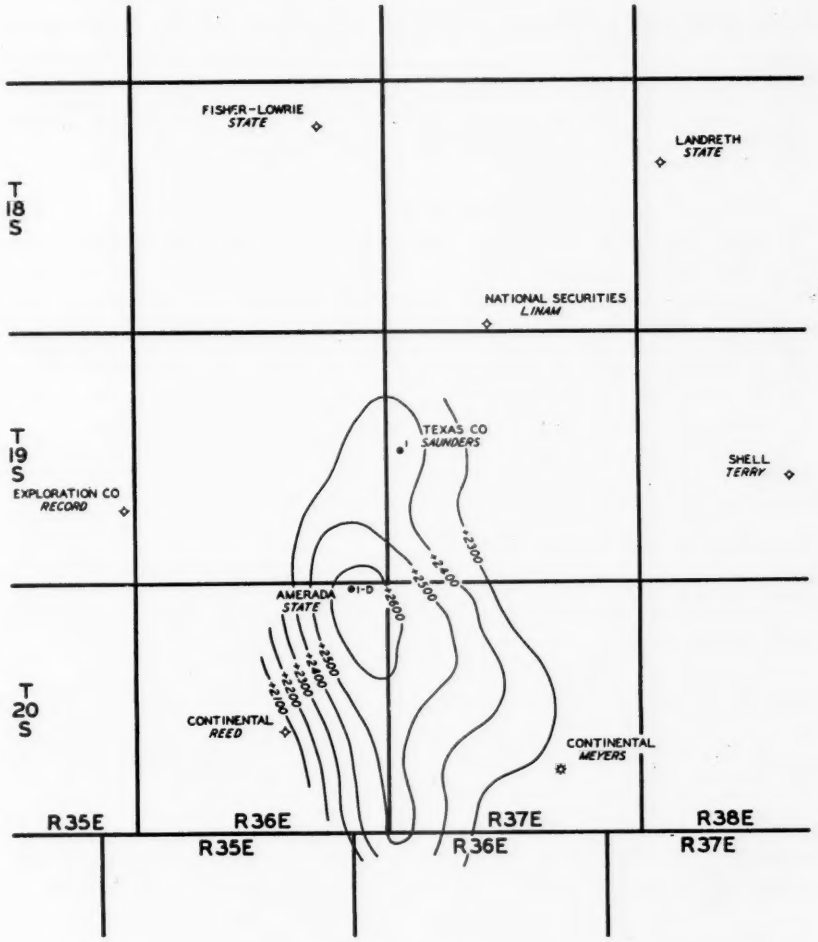

FIG. 6. Contour map on base of Red Beds. From sample logs of wells in Monument Field. Contour interval 100 feet.

DISCUSSION

Although the Monument Field was discovered by other means, the resistivity survey here discussed did successfully outline the structural anomaly, and yielded a fairly accurate detailed picture. It must be emphasized that the striking success of the resistivity survey in this case resulted from the recognition of a geological section which lent

itself to this type of survey. The resistivity anomaly over this structure is not a near-surface effect, but is a direct result of the uplift of a thick bed of material which can be considered to be an electrical non-conductor. The anomaly so produced is of sufficient magnitude that it can be readily observed and easily interpreted.

ACKNOWLEDGEMENT

The author wishes to thank the Geophysical Research Corporation and the Amerada Petroleum Corporation for making available the data for this paper; Mr. W. T. Born for his aid in the preparation of the paper, and Mr. W. A. Carruth and Mr. A. E. Smith, who prepared the drawings for the figures.

A PROPOSED METHOD OF MEASURING THE DERIVATIVES OF THE EARTH'S MAGNETIC FIELD*

J. H. JONES†

ABSTRACT

The method of measuring the derivatives of the earth's magnetic field which is proposed depends on the fact that a small steady magnetic field will modify the e.m.f. induced in the secondary coil of a detector with a core of magnetizable material possessing high initial permeability and a high rate of increase of the permeability with the strength of the magnetizing field. It is shown that a detector of this type is equivalent to an inductor coil rotating with angular speed equal to the periodicity of the alternating magnetizing field.

INTRODUCTION

Attempts have been made in the past to develop an instrument for measuring the derivatives of the earth's magnetic field, corresponding to the Eötvös Balance for gravity measurements, but hitherto no practical field instrument appears to have been evolved.

It is true that the modern field magnetometers, which measure the variations in the magnetic intensity (chiefly the vertical component) are very reliable, easy to manipulate, and inexpensive to maintain in the field, so that the demand for an instrument which measures the derivatives of the magnetic field has not been very urgent.

Nevertheless the measurement of the derivatives, if practicable, would have very definite advantages in certain investigations, for example, in those cases in which the disturbance of the normal field is small and limited in extent. Another advantage, and this is a very important one, is that the values of the derivatives are virtually unaffected by the diurnal variations in the intensity. The method of measuring the derivatives which is proposed in this paper is the outcome of a special investigation undertaken by the writer about a year ago. It appears from recent information, however, that the basic principle of the method is not entirely novel,[1] but it is hoped that the theoretical treatment of the problem presented in this paper will prove useful and that its publication is justified.

* Read by title at the Annual Meeting, Denver, Colorado, April, 1942.

† Gulistan, Gang Hill, Guildford, Surrey. Formerly Chief Geophysicist, Anglo-Iranian Oil Company.

[1] See reference to U.S. Patent No. 2,252,059 in GEOPHYSICS Vol. VI, No. 4, p. 457, (October, 1941).

THEORETICAL BASIS OF THE METHOD

Let us suppose that primary and secondary coils are wound on a long cylinder of magnetizable material which possesses a high initial permeability coefficient and a high rate of increase of this coefficient with the strength of the magnetizing field. Pure soft iron has this property and we shall assume that the cylindrical cores are made of this substance.

We shall neglect, in the first place, the effects of hysteresis and for

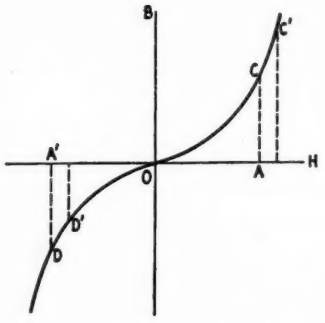

FIG. 1. A portion of an hypothetical B–H curve, in which it has been assumed that B is a single valued function of H.

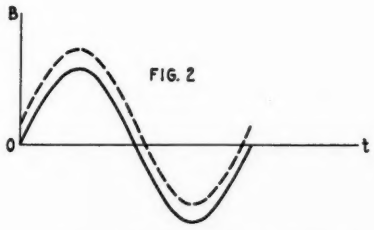

FIG. 2. Illustrating the distortion of the original flux-time curve (solid line) by the application of a small steady magnetizing force.

simplicity assume that the B–H values are reversible so that B is a single-valued function of H. A hypothetical B–H curve is shown in Fig. 1. Let us suppose that the magnetizing field H goes through a cycle of changes, starting at zero, increasing to the value OA, back to zero, and on to OA' in the reverse direction and back again to zero.

We shall assume that the cycle of changes in the magnetising field are simple harmonic and represented by:

$$H = H_0 \sin \omega t. \tag{1}$$

The flux-time curve will be something like that shown in full line in Fig. 2. On account of the variations in the permeability with the strength of the magnetizing field the flux-time relation is not simple harmonic in character, but it can be expressed by a Fourier series:

$$\begin{aligned} B = F(t) = {} & A_1 \sin \omega t + A_2 \sin 2\omega t + A_3 \sin 3\omega t + \cdots \\ & + B_1 \cos \omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + \cdots . \end{aligned} \tag{2}$$

Let us consider the effect of applying a small steady magnetising field of strength h, so that the curve DOC (Fig. 1) is displaced to the right of the diagram to the position $D'OC'$. The new flux-time curve will be slightly different in shape as represented by the broken line in Fig. 2, and in consequence the induced e.m.f. in a secondary coil will be altered.

The change in the flux ΔB at any time t will be represented, to a first approximation by:

$$\Delta B = h\frac{dB}{dH} = hF'(t)\frac{dt}{dH} \tag{3}$$

and the differential e.m.f. by:

$$-\frac{d}{dt}(\Delta B) = -h\frac{d}{dt}\left\{F'(t)\frac{dt}{dH}\right\}. \tag{4}$$

THE EFFECT OF HYSTERESIS

In general, on account of hysteresis, the flux B is not a single-valued function of the magnetizing field H, and the B–H diagram becomes a closed curve as shown in Fig. 3 (full line).

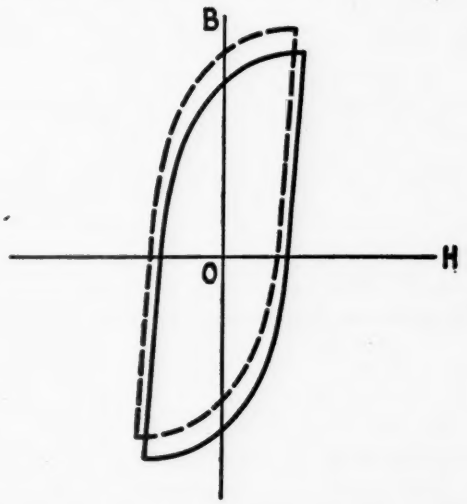

FIG. 3. Illustrating a more general B–H relation (solid curve), and its distortion by the application of a small steady magnetizing force, resulting in the generation of even-order harmonics.

When there is no steady applied field, the opposite quadrants of the hyteresis curve are symmetrical and the corresponding flux-time curve has symmetry in successive half wave-lengths because equal and opposite values of the flux occur in order.

This means that the odd harmonics only are present, and the expression for the flux is:

$$B = F(t) = A_1 \sin \omega t + A_3 \sin 3\omega t + A_5 \sin 5\omega t + \cdots + B_1 \cos \omega t + B_3 \cos 3\omega t + \cdots . \tag{5}$$

If, however, the hysteresis curve is not symmetrical in opposite quadrants due to the application of a steady field, we must include the even harmonics in the expression for $F(t)$.

However, when the steady field is small compared to the rapidly alternating magnetizing field, the amplitudes of the even harmonics will be small compared to those of the odd harmonics, and we shall assume in the first place that the flux-time relation is represented by (5).

The differential e.m.f. given by (4) can now be evaluated. We shall first consider the value of $F'(t)dt/dH$ for the n^{th} term in the Fourier series.

Writing

$$\frac{dt}{dH} = \frac{1}{H_0 \omega \cos \omega t},$$

we have

$$\left[F'(t)\frac{dt}{dH}\right]_n = \frac{1}{H_0 \omega \cos \omega t}\left[A_n n\omega \cos n\omega t - B_n n\omega \sin n\omega t\right]$$

$$= \frac{1}{H_0}\left[A_n n\{\cos (n-1)\omega t - \sin (n-1)\omega t \tan \omega t\}\right.$$

$$\left. - B_n n\{\sin (n-1)\omega t + \cos (n-1)\omega t \tan \omega t\}\right].$$

We have to rewrite the terms in tan ωt. Thus

$$\begin{aligned}
&\sin (n-1)\omega t \tan \omega t \\
&= \{\sin (n-2)\omega t \cos \omega t + \cos (n-2)\omega t \sin \omega t\} \tan \omega t \\
&= \sin (n-2)\omega t \sin \omega t + \cos (n-2)\omega t \sin^2 \omega t \sec \omega t \\
&= \cos (n-2)\omega t \cos \omega t - \cos (n-1)\omega t + \cos (n-2)\omega t \sin^2 \omega t \sec \omega t \\
&= -\cos (n-1)\omega t + \cos (n-2)\omega t \sec \omega t.
\end{aligned}$$

But

$$\cos (n-2)\omega t \sec \omega t = \cos (n-3)\omega t - \sin (n-3)\omega t \tan \omega t$$

so that

$$\sin (n-1)\omega t \tan \omega t = -\cos (n-1)\omega t + \cos (n-3)\omega t - \sin (n-3)\omega t \tan \omega t.$$

By symmetry we can write

$$\sin (n-3)\omega t \tan \omega t = -\cos (n-3)\omega t + \cos (n-5)\omega t - \sin (n-5)\omega t \tan \omega t.$$

We get finally the following expression:

$$\sin (n-1)\omega t \tan \omega t = -\cos (n-1)\omega t + 2\cos (n-3)\omega t - 2\cos (n-5)\omega t + 2\cos (n-7)\omega t + \cdots + 2\cos (n-n)\omega t.$$

Similarly

$$\cos (n-1)\omega t \tan \omega t = \sin (n-1)\omega t - 2\sin (n-3)\omega t + 2\sin (n-5)\omega t - 2\sin (n-7)\omega t + \cdots + 2\sin (n-n)\omega t \pm \tan \omega t.$$

The sign of the last term depends on the value of n and will be alternately positive and negative in the series.

Thus the value of $F'(t)dt/dH$ for the n^{th} term in the series becomes

$$\left[F'(t)\frac{dt}{dH}\right]_n = \frac{1}{H_0}\left[A_n n\{2\cos (n-1)\omega t - 2\cos (n-3)\omega t + 2\cos (n-5)\omega t + \cdots + 2\} - B_n n\{2\sin (n-1)\omega t - 2\sin (n-3)\omega t + 2\sin (n-5)\omega t + \cdots \pm \tan \omega t\}\right].$$

Since the flux $F(t)$ is maximum when the magnetizing force is maximum, that is, when $\omega t = \pi/2, 3\pi/2, 5\pi/2$ etc., we have the relation

$$B_1 - 3B_3 + 5B_5 - 7B_7 + \cdots = 0. \tag{6}$$

Substituting the value of $F'(t)dt/dH$ in (4) and making use of (6) we get the following expression for the differential e.m.f.

$$\Delta e = \frac{4h\omega}{H_0}\left[(3A_3 - 5A_5 + 7A_7 - \cdot)\sin 2\omega t + (3B_3 - 5B_5 + 7B_7 - \cdots)\cos 2\omega t\right] + \text{higher order even harmonic terms.} \tag{7}$$

Thus the effect of a small steady applied field is to introduce even harmonics into the e.m.f. induced in the secondary coil.

When the hysteresis curve is known, all the coefficients A_3, $A_5 \cdots$ B_3, $B_5 \cdots$ can be determined by the usual Fourier rule.

EFFECT OF A STRONG STEADY FIELD

The application of a strong steady field will cause asymmetry in the B–H diagram and we must introduce the even harmonics in the expression for $F(t)$, so that in general.

$$F(t) = A_0 + A_1 \sin \omega t + A_2 \sin 2\omega t + A_3 \sin 3\omega t + \cdots + B_1 \cos \omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + \cdots . \tag{8}$$

The hysteresis curve will not be symmetrical in opposite quadrants, but it will be displaced along the B and H axes and it will be distorted in shape relative to the curve with no steady applied field (Fig. 3, broken line).

Using the relations (4), (6) and (8) we can deduce the expression for Δe in this more general case, and it will be seen that there is a term involving the fundamental frequency $\omega/2\pi$. The value of this term is

$$\Delta e = \frac{4h\omega}{H_0}(B_2 - 2B_4 + 3B_6 - 4B_8 + \cdots) \cos \omega t, \tag{9}$$

where h is again a small change in the steady field.

It is interesting to compare the expression (9) with that for the e.m.f. induced in a coil rotating with angular velocity ω.

The flux through the coil at any time t due to the field h is given by $B = hA \sin \omega t$, where A is the effective area of the coil.

The e.m.f. induced in the coil will be given by

$$\frac{dB}{dt} = hA\omega \cos \omega t.$$

Comparing with expression (9) we see that the solenoid detector is equivalent to a coil rotating with an angular speed ω, the periodicity of the alternating magnetizing field, and having an effective area given by

$$A = \frac{4}{H_0}(B_2 - 2B_4 + 3B_6 - 4B_8 + \cdots).$$

EXPERIMENTAL ARRANGEMENT

The proposed experimental arrangement for measuring the derivatives of the earth's magnetic field is shown in Fig. 4. The arrangement has been designed for observing changes in the fundamental vibration but it can be modified for observing changes in the first harmonic.

The two magnetizing coils P_1 and P_2, which are approximately identical, are connected in series to a high voltage generator giving a

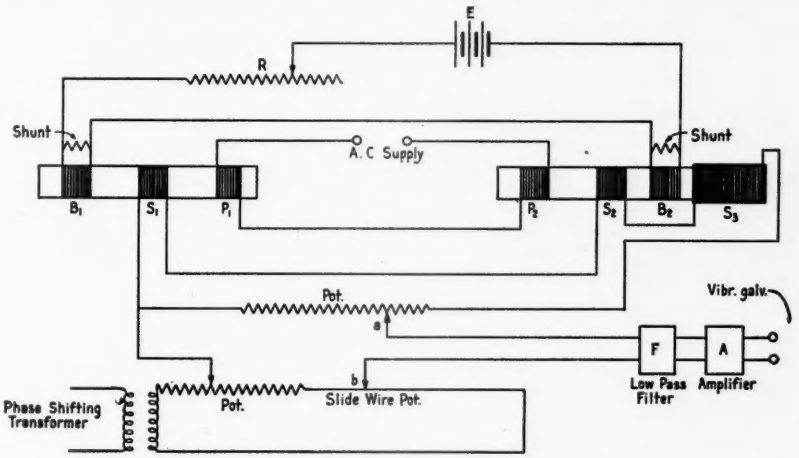

FIG. 4. An experimental arrangement for measuring the derivatives of the earth's field, arranged for observing changes of level at the fundamental frequency of the A.C. supply.

simple harmonic electromotive force. The magnetizing current, which must also be simple harmonic, must be sufficiently strong to produce a magnetizing force of about 1 oersted. The secondary coils S_1 and S_2, also approximately identical, have a large number of turns and are connected in opposition. A small auxiliary balancing coil S_3 is included in the secondary circuit. This coil, which is movable, is located near the end of one of the solenoid detectors. The two other coils B_1 and B_2 are connected through a rheostat to a battery E. Each of these coils has a variable high resistance shunt connected across the terminals so that the strength of the steady magnetizing field can be finely controlled in each solenoid. This arrangement will also serve as an additional control on the balance of the opposing e.m.f.

The residual e.m.f. is finally balanced by the potential drop in the slide wire of an A.C. potentiometer of the Drysdale-Tinsley type.

The two contacts at a and b on the high and low resistance potentiometer are connected to the input terminals of a low pass filter F attached to the low frequency amplifier A. The filter will cut off all the harmonics of the fundamental note. The output terminals of the amplifier are connected to a vibration galvanometer tuned to the frequency of the fundamental note.

If is hardly necessary to add that the detectors must be well shielded from temperature changes.

In order to determine the gradient of the magnetic field in any direction, it will be necessary to set the detectors along this direction at a suitable distance apart and to obtain a balance in the manner described above. One of the detectors is then moved through a distance x and the galvanometer deflection recorded. This deflection will be proportional to $x\partial X/\partial x$, where $\partial X/\partial x$ represents the gradient. The sign of the gradient can be found by observing the change in the galvanometer deflection by the field of a permanent magnet placed near one of the detectors.

The gradient in the y direction can be measured in a similar manner and the magnitude and direction of the resultant gradient in the xy plane can then be determined.

ESTIMATE OF THE SENSITIVITY OF SOFT IRON DETECTORS

Let us suppose that the flux-time relation is represented by the simple expression

$$\begin{aligned} B = F(t) &= A_1 \sin \omega t + A_3 \sin 3\omega t \\ &= (A_1 + 3A_3) \sin \omega t - 4A_3 \sin^3 \omega t \\ &= \left(\frac{A_1 + 3A_3}{H_0}\right) H - \frac{4A_3}{H_0^3} H^3, \end{aligned}$$

so that

$$\frac{dB}{dH} = \frac{A_1 + 3A_3}{H_0} - \frac{12A_3}{H_0^3} H^2.$$

Writing $B = SB_1$, where B_1 is the flux per unit area and S the effective area of the secondary coil, we have

$$\begin{aligned} \frac{dB_1}{dH} &= \frac{A_1 + 3A_3}{SH_0} - \frac{12A_3H^2}{H_0^3} \\ &= \alpha + \beta H^2. \end{aligned}$$

Assuming that for $H_0 = 1$ oersted the numerical value of β is of the order of 10^2, and that the effective area $S = 3 \times 10^4$ cm^2, the numerical value of A_3 will be 0.25×10^6. Referring to (7) we get on writing $x\partial X/\partial x$ for h,

$$\Delta e = 12x \frac{\partial X}{\partial x} \omega A_3 = 3x \frac{\partial X}{\partial x} \omega \times 10^6$$

or

$$\frac{\partial X}{\partial x} = \Delta e/(3\omega x \times 10^6).$$

With $\Delta e = 10^{-6}$ volt (10^2 e.m. units), which should be detectable, $\omega = 300$ radians/sec., $x = 100$ cms., we get approximately,

$$\frac{\partial X}{\partial x} = 10^{-9} \text{ oersted/cm.}$$

GRAVITY AND MAGNETIC OBSERVATIONS ON IRON MOUNTAIN MAGNETITE DEPOSIT, LLANO COUNTY, TEXAS*

VIRGIL E. BARNES† AND FREDERICK ROMBERG‡

ABSTRACT

An outcrop of magnetite in the Central Mineral region of Texas is explored experimentally with a dip needle and a gravity meter. Two anomalies are observed, one due to the outcropping body and one probably due to a previously unknown body close to the outcrop. The possible attitudes of the bodies are discussed, and their masses and probable dimensions are computed from the gravitational observations.

INTRODUCTION

This paper concerns a small body of magnetite, whose existence has been known for some time, and in whose vicinity a considerable amount of tunnelling and drilling has been done in an unsuccessful attempt to find more ore. The vicinity of the ore body was recently explored with a combination of magnetic and gravitational observations, with interesting results. The magnetic data showed a probable new ore body which had been missed by the previous exploration, and the gravity data gave a basis for estimating the attitude and size of the new body, besides furnishing a revised estimate of the mass of the known body. While no new methods are used in the interpretation of the observed data, the present treatment is offered as a concrete example of methods which have been widely discussed in theory but perhaps not sufficiently well illustrated.

DESCRIPTION OF PROSPECT

Magnetic iron ore outcrops have been reported in many localities of the Central Mineral region of Texas, and several of these have been mapped and described by Paige.[1] From his descriptions of various prospects, Iron Mountain was chosen as the one about which the most is known and which should therefore be best suited for correlation of magnetic and gravity observations with the materials present.

* Presented at the Denver meeting, April 1942. Published with permission of E. H. Sellards, Director, Bureau of Economic Geology, The University of Texas, Austin Texas.

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[1] Paige, Sidney, *Mineral resources of the Llano-Burnet region, Texas*: U. S. Geol. Survey Bull. 450, pp. 26–70, 1911.

Iron Mountain is located 12 miles airline northwest of Llano and one mile northwest of Valley Spring. It is situated in an area of pink feldspathic gneiss of pre-Cambrian age, named by Paige the Valley Spring gneiss. The area covered by this investigation has few outcrops, but from dumps, test pits, scattered outcrops, and the uni-

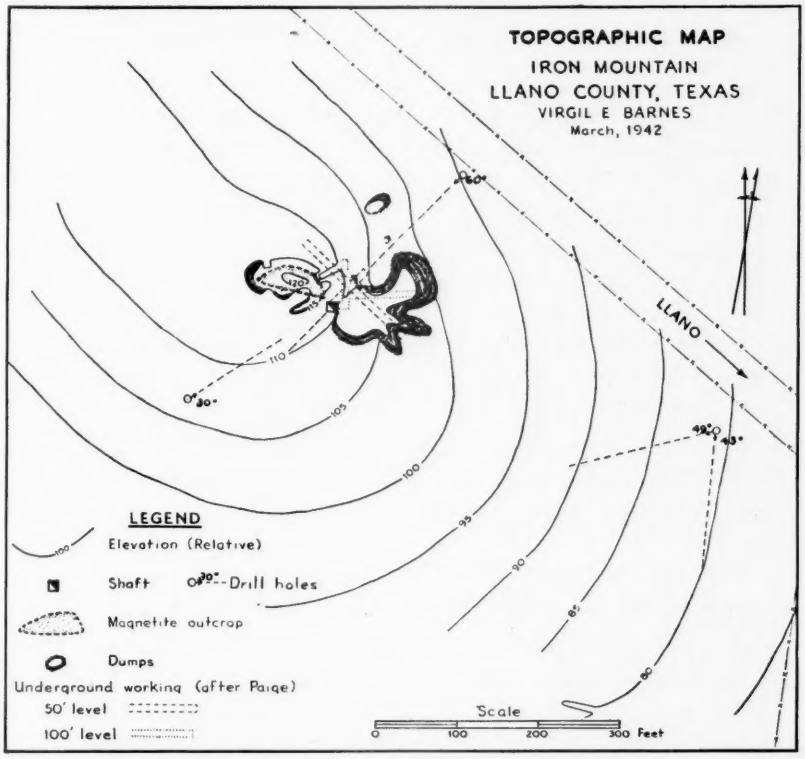


FIG. 1. Topographic map of Iron Mountain, Llano County, Texas.

formity of soil and vegetation it is apparent that Valley Spring gneiss is the predominant rock, and that other rocks, excluding iron ore, are limited to pegmatite, aplite, and some schist.

The iron ore is composed chiefly of the mineral magnetite, which outcrops over an area about 85 by 30 feet in size (see Fig. 1). The ore has a well-developed mineral alignment pitching 22° to the southeast. Paige lists twelve analyses of the ore ranging from 58.87 to 67.60 per cent metallic iron. The specific gravities of two samples are listed as

4.724 and 4.677, or an average of about 4.70. The specific gravity of the Valley Spring gneiss has not been determined, but similar rocks from other areas average about 2.65. A test pit 5 feet square, recently dug at the southeastern end of the outcropping magnetite mass, exposes an aplite sharply bounding the magnetite. The test pit is entirely in aplite, and since there are no surface exposures, the size and trend of the cross-cutting aplite cannot be stated.

APPLICATION OF THE DIP NEEDLE TO MAGNETIC PROSPECTING

Dip-needle surveys have been widely used to delineate areas of major variations in the earth's magnetic field caused by concentrations of magnetic minerals. When small variations in the earth's field are being studied, more refined instruments are used, but these refinements are of little value in areas containing deposits of magnetite; therefore, the less sensitive dip needle is considered the logical instrument to use in magnetic exploration for magnetite. The principles, construction, and operation of the dip needle are discussed by Stearn.[2] The assembling and interpretation of dip-needle data have been furthered by governmental and private agencies, notable among which is the Wisconsin Geological Survey. Aldrich[3] demonstrates the interpretation of some of the Wisconsin dip-needle observations in an area where outcrops are so sporadic that interpretation of the geological features without magnetic observations is highly unsatisfactory.

MAGNETIC DATA ON IRON MOUNTAIN

Much of the magnetite-bearing portion of the Central Mineral region is poorly exposed, and supplementary data are needed to outline magnetic deposits. Iron Mountain was chosen as a preliminary locality to study the possible advantage of combined magnetic and gravity prospecting in the Central Mineral region. Dip-needle observations were made at 50-foot intervals near the outcropping magnetite mass, and the 50-foot grid was then extended to cover the area of anomalous magnetic values.

In Fig. 2 the dip-needle observations are shown by contours. (The contours are an expression of the position assumed by the dip needle

[2] Stearn, N. H., The dip needle as a geological instrument. *Geophysical Prospecting*, pp. 345–363, Amer. Inst. Min. Met. Eng., New York, N. Y., 1929.

[3] Aldrich, H. R., A demonstration of the reflection of geologic conditions in observed magnetic intensity. *Geophysical Prospecting*, pp. 385–400, Amer. Inst. Min. Met. Eng., New York, N. Y., 1929.

and do not represent a component of the earth's field.) Four magnetic poles are shown, indicating two distinct magnetic bodies. The two smaller magnetic poles are related to the outcropping magnetite mass. The two larger ones are related to a mass that does not outcrop and which has hitherto not been found by any recorded drilling or under-

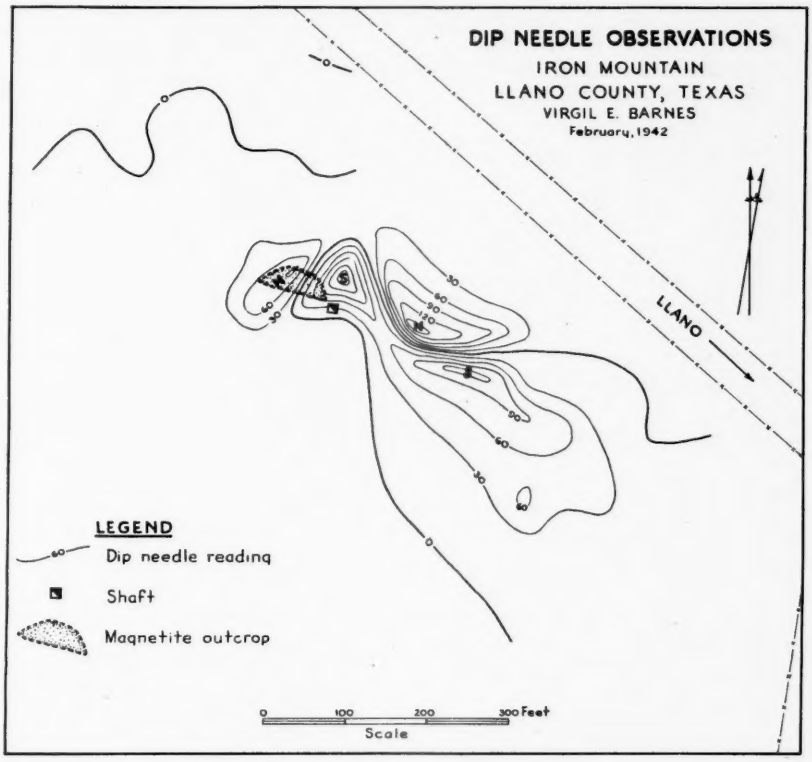


FIG. 2. Dip-needle observations on Iron Mountain, Llano County, Texas.

ground workings. It seems likely that the aplite in the previously mentioned test pit has completely cut across the magnetite mass, dividing it into two separate bodies. It is interesting that Paige (*op. cit.*) lists several drill holes (see Fig. 1), totaling 2390 feet, drilled in the hope of finding magnetite. A day's work with the dip needle would have shown the proper place to drill. It is also noteworthy that the unknown mass lies in the direction of the mineral alignment of the outcrop.

GRAVIMETRIC DATA

The measurements of gravitational force were made with a gravity meter whose dial ratio had been increased by a factor of five to reduce the reading error. The area was covered with a 100-foot grid of gravity stations, and a few fill-in stations were later added. Sixteen of the

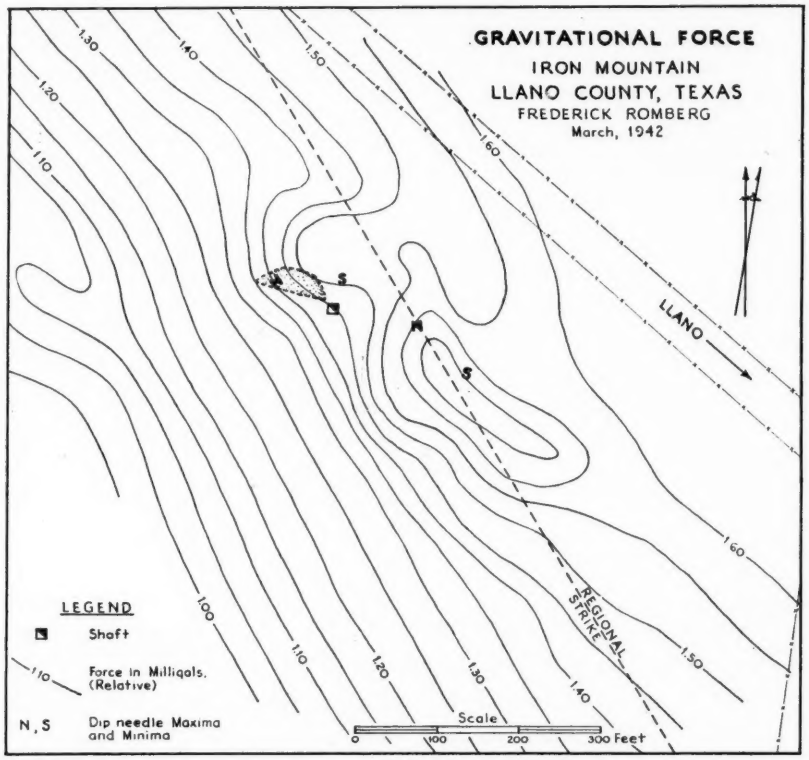


FIG. 3. Gravitational force before subtraction of regional gradient, Iron Mountain, Llano County, Texas.

stations were repeated for a check on accuracy, and the average difference was found to be 0.01 milligal. Terrain corrections were made with a Hammer zone chart,[4] using an assumed surface density of 2.65. The maximum terrain correction was 0.06 milligal, and only three stations had a terrain correction larger than 0.02.

[4] Hammer, Sigmund, *Terrain corrections*. GEOPHYSICS, Vol. 4, No. 3, p. 184 (July 1939).

Fig. 3 shows the gravity readings after all the routine corrections had been made. The locations of the observed magnetic poles are shown by the symbols *N* and *S*. It can be seen that the gravitational field is considerably disturbed in the neighborhood of these poles; there is evidently a strong gravitational response to the known

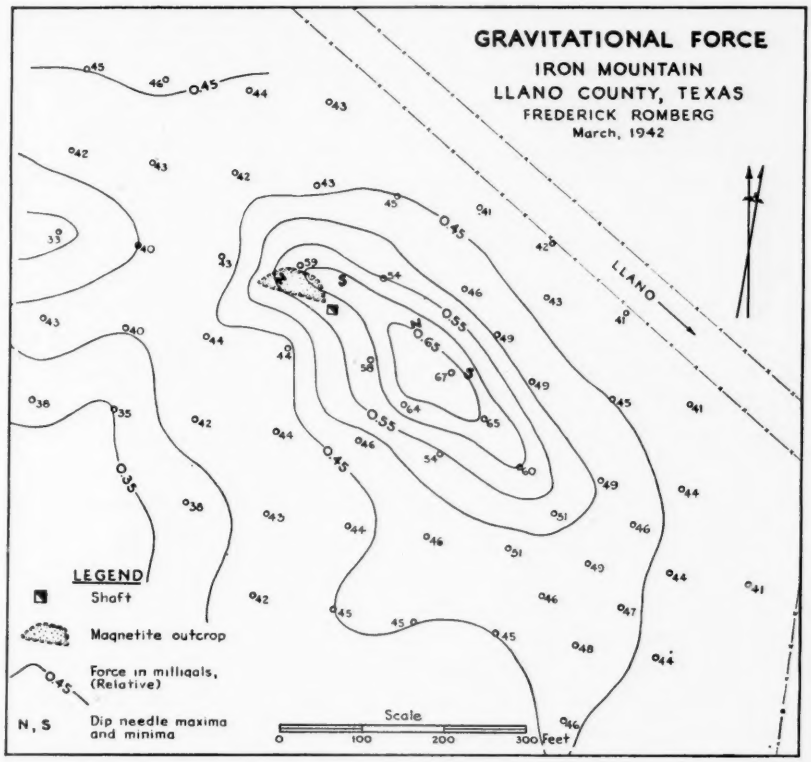


FIG. 4. Gravitational force after subtraction of regional gradient, Iron Mountain, Llano County, Texas.

and suspected ore bodies. However, the most obvious feature of the map in Fig. 3 is a large and well-defined regional gradient. The strike of the gradient is NW–SE and its magnitude about 0.1 mg. per hundred feet. Clearly, before the effects of the ore bodies could be studied further, the observations had to be corrected by subtracting the effect of the regional gradient. The propriety of making such corrections was checked by observations at a distance from the prospect, and it

was found that the gradient persisted, with a constant magnitude and direction, for at least two miles.

Fig. 4 shows the gravity readings after the gradient has been subtracted. The obscure swirls of the uncorrected map resolve themselves into a clearly defined anomaly superimposed on a relatively smooth background. The magnitude of the anomaly is over twenty times the probable error of a single observation, so there can be no doubt of its significance. The effect of the known ore body can be seen in the bulge of the contours at the northwest end of the anomalous figure. The contours southeast of the known body show that there is a previously undiscovered anomalous mass, located in general conformity with the second pair of magnetic poles. The gravity results agree with the magnetic ones in suggesting that the unknown, anomalous body is more important than the known one. It is to be noticed that the magnetic map resolves the two bodies, while the gravity map does not; this conforms with the theory, which shows that since the magnetic effect dies out faster with distance than the gravitational effect, it has more resolving power in the region where it is perceptible.

INTERPRETATION

The interpretation of the Iron Mountain gravity anomaly is an especially easy type problem because of its small geographical scale, the simple terrain corrections, the probably constant density anomaly, and the probably compact shape of the ore body.

Consider first the known ore body. Paige (*op. cit.*) describes it as "a nearly vertical mass of very pure magnetite" 22 to 25 feet wide and about 100 feet long. He finds from mining data that it is deeper than 50 feet but not so deep as 100. The ore has been taken from the surface so that the present length of the outcrop is about 85 feet. The purpose now is to study the theoretical correspondence between the known mass and its effect on the gravity meter.

The gravitational effect of the known body, as stated above, consists of a bulge in the contours at the northwest end of the anomalous gravity values. The height of the bulge is shown in Fig. 5, which is a cross section of the gravitational force in a line going roughly north and south through the middle of the outcrop. The cross section shows a single high point, about 0.16 mg above the background; the observations nearest to this high point, only about 100 feet from it, have practically the background value. Now since at a lateral distance of

100 feet the effect of the mass has practically disappeared, its average depth (if the mass is compact) must be less than half that distance.

To make the problem quantitative, it can be assumed that the known ore body has the shape assigned to it by Paige and its depth computed. If it is represented as an upright slab of known length, thickness, and anomalous density, then the depth of the bottom of the

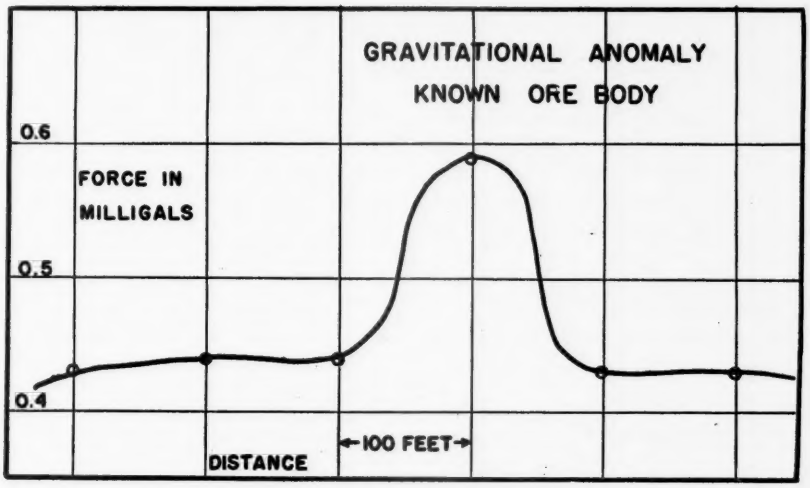


FIG. 5. Gravitational force in a profile across the known ore body, Iron Mountain, Llano County, Texas.

mass can be computed from the height of the anomaly observed over its center (see APPENDIX, Eq. 2). Suppose the ore body is taken to be 85 feet long and 20 wide, the anomalous density 2, and the anomalous force (estimated from the map rather than from the cross section) 0.18 mg, measured at a point 10 feet above the average top of the outcrop. Then the depth comes out to be 36 feet. This is much smaller than the 50 feet given by the mining data and shows that there should be considerably less ore in the known body than Paige assumes. That is, the known ore body must now be thought of as being discontinuous in depth, or else as being thinner or shorter than was originally supposed.

Another way to get a quantitative answer concerning the ore body is to assume that the length and depth are known, and find the thickness. If the depth is taken to be 60 feet, then the width is about 14 feet.

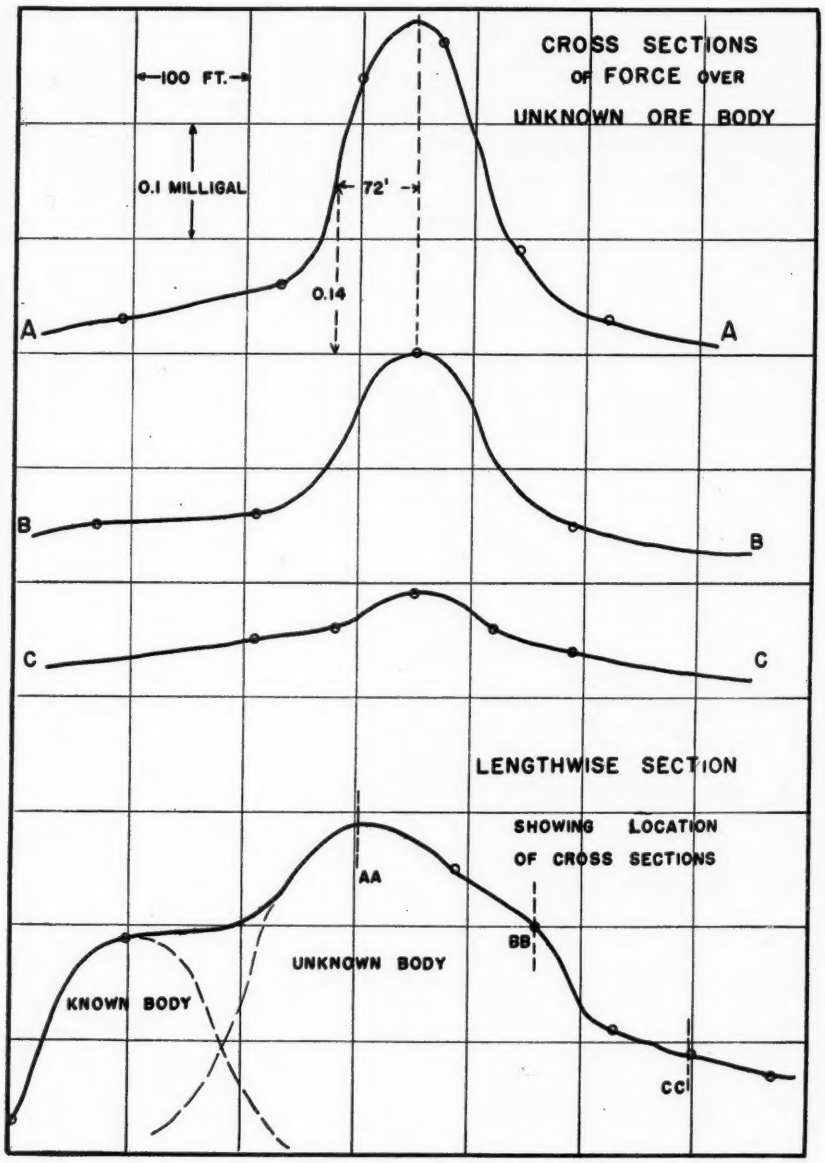


FIG. 6. Sections showing anomalous force over ore bodies, Iron Mountain, Llano County, Texas.

These two assumptions yield, respectively, masses of 5500 and 3900 metric tons for the known body, as compared with an estimated mass of 8500 tons from the dimensions that were assumed from the mining data.

INTERPRETATION: THE UNKNOWN BODY

The gravity anomaly caused by the unknown body can best be studied with cross sections and a lengthwise section; these are shown in Fig. 6. The lengthwise section shows, of course, the effects of both the known and unknown bodies, but since the known body appears to be cut off not far from the end of the outcrop, a limit can be assigned to its gravitational effect, which will leave the remainder of the anomaly to be caused by the unknown body. The presumable division between the effects of the two bodies is shown by dotted lines in the figure.

The lengthwise section shows the anomaly to be fairly sharply cut off at both ends, indicating that the body is perhaps 200 feet long. The contours show that the body is narrow and fairly straight. Since the contour figure is flatter at the southeast end than at the northwest, but just as wide, the body probably plunges somewhat to the southeast.

Beyond these general considerations the interpretation of the body is, of course, guess-work, since there is an infinite number of possible masses that could cause the observed effect. For an extreme example, the effect could be produced by a shallow lens of ore spread over the whole extent of the gravity anomaly. However, in view of the apparently compact shape of the known body, it is reasonable to assume that the unknown body is also compact. It could be a cylindrical or cigar-shaped body, or it could be, as appears likely, a slab-like body whose depth is greater than its width.

To study the body quantitatively it must be assumed that it has a definite (and preferably a simple) shape. For the reasons mentioned above it is assumed that its length is known but not its height or width. If in addition it is assumed that the body is taller than wide, then it can be treated as a thin upright slab. There are now three unknown variables: the depth to the top of the slab, the depth to the bottom, and the thickness.

For the computations one equation can be written (see APPENDIX, Eq. 1) using the maximum height of the anomaly, and another using the width of the anomalous figure at half-height. The cross section gives these as 0.29 mg and 72 feet respectively. However, to de-

termine the three unknowns one more equation is necessary. Such an equation could be written involving, say, the width of the anomaly at quarter-height, but for this case neither the measurements nor the assumptions are accurate enough to warrant a third equation. It will be better to set one of the unknowns at different arbitrary values and examine the possible resulting values of the others. This process, when it is carried out, shows that the unknowns remain within practical limits which are good indices of the worth of the gravity results.

The above-mentioned equations, when they are solved in the manner suggested, show that, for one extreme, the ore body is not likely to be thinner than 15 feet. In this case its top will be shallow (about 30 feet) and its bottom very deep (perhaps 200 feet). For the opposite extreme, the body may be as thick as 30 feet. Then its top will be 60 feet deep and its bottom only 90. Thus the body can be either a thin sheet which begins close to the surface and extends to a great depth, or it can be a thick bar, so to speak, at a medium depth. A reasonable compromise gives 23 feet for the thickness, 45 feet for the depth to the top, and about 160 for that to the bottom. These estimates for the dimensions and attitude of the unknown body are, of course, not to be taken literally. They do, however, make possible a geological view of the ore body which forms a practical basis for exploitation.

The mass of what is probably ore, as computed from the compromise dimensions, is about 40,000 metric tons. The mass can also be estimated by integrating graphically the "volume" of the anomaly (see APPENDIX, Eq. 3). This process yields a minimum for the total mass of 45,000 tons, which shows that the compromise dimensions above are conservative, even when the mass of the known body is subtracted from the total.

CONCLUSION

The specific value of the conclusions drawn from the geophysical data from Iron Mountain is fairly clear since previous exploration without geophysical methods proved to be expensive and ineffective. It may be suggested in addition that the combination of the gravitational method with a fast and cheap discovery method, such as dip-needle observations, presents possibilities for prospecting that have not been well explored. Few mining problems, of course, can be solved by so simple an application of magnetic prospecting, and few gravity anomalies can so easily be studied in a quantitative way, as this one.

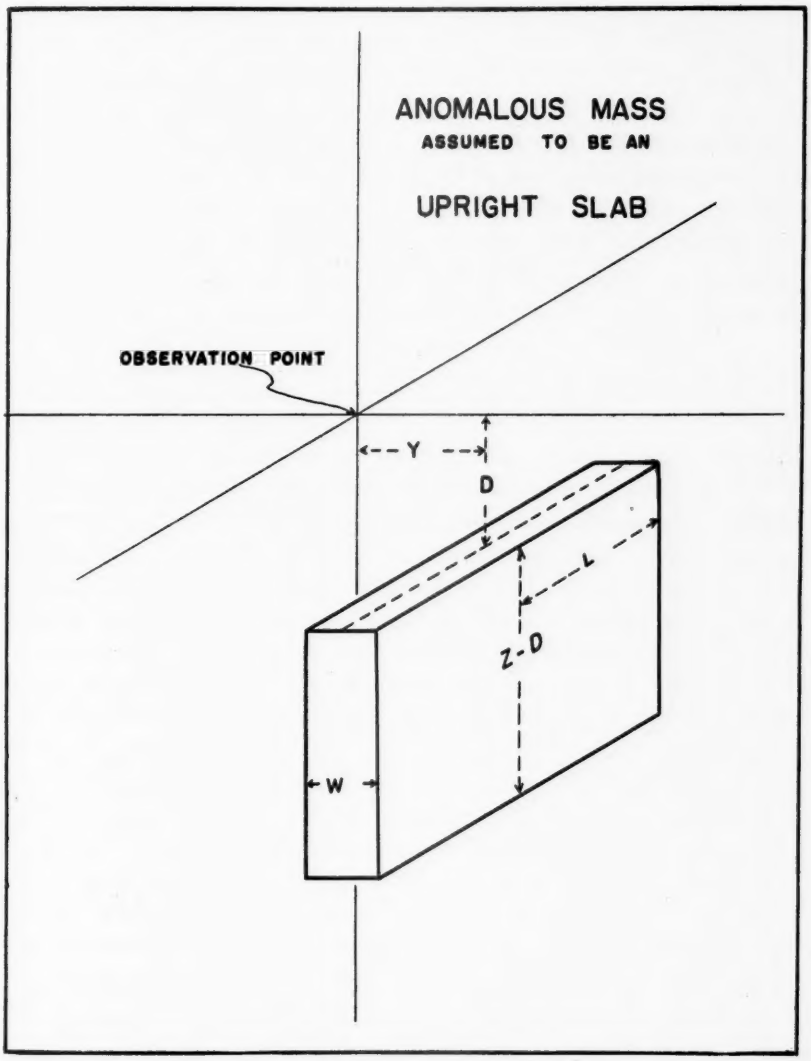


FIG. 7. Shape of anomalous mass assumed for computations, Iron Mountain, Llano County, Texas.

However, it may be that the use of geophysical methods in general prospecting has lagged because the proper combinations have not been tried or examples of their use have not been available. The problems cannot be treated as routine ones, as they are in some kinds of oil

prospecting, and progress with them will not be made without more pioneering.

APPENDIX

The quantitative results given in the text of the paper are all based on an expression for the gravitational force of a thin upright slab (Fig. 7) at a point which is a distance d upward and y outward from the middle of its upper edge. Let the length of the slab be $2l$, its height $z-d$, and its width w, and let it have the anomalous density s. Then the downward force F will be

$$F = ksw \log \left[\frac{\sqrt{l^2 + y^2 + d^2} - l}{\sqrt{l^2 + y^2 + d^2} + l} \frac{\sqrt{l^2 + y^2 + z^2} + l}{\sqrt{l^2 + y^2 + z^2} - l} \right] \qquad (1)$$

where k is the gravitational constant.

In the computations for the unknown body the main cross section yielded values of F for y equals 0 and y equals 72 feet. The resulting two equations, when they were combined, made a single equation in which d and z were still unknown. If one of these variables was set arbitrarily the other one was then determined (from a graphical solution); w could then be found from one of the original equations.

When the known body was under consideration the thickness was computed by assuming that the length, height, and depth were known. If, in Eq. 1, y is set equal to zero, the equation can be solved for w. Another computation was made, in which l, w, and d were assumed known and z was found. As a first approximation, y was set to zero in Eq. 1 and the equation solved for z, but this involved the assumption that the mass was concentrated in a vertical plane directly below the instrument, and yielded a doubtful answer because the instrument was so close to the top of the slab. A refinement was made by letting the mass be concentrated in two vertical planes each a quarter of the total width out from the original central plane. The depth to the bottom, z, was then given by the expression

$$z = \sqrt{\frac{4l^2AB}{(1 - AB)^2} - \left(\frac{w}{4}\right)^2} \qquad (2)$$

in which

$$A = e^{F/ksw} \quad \text{and} \quad B = \frac{\sqrt{l^2 + (w/4)^2 + d^2} - l}{\sqrt{l^2 + (w/4)^2 + d^2} +}.$$

It is possible to write equations giving more detail about the anomalous bodies, but such equations would depend on further assumptions about the shape of the bodies. In the present case any more assumptions would be unwarranted.

The mass causing the gravitational anomaly is computed, first, from the dimensions and density of the ore body, and, second, by estimating the "volume" of the anomalous figure. This "volume" is proportional to the mass, according to the expression

$$M = \frac{\sum F \Delta A}{\pi k} \tag{3}$$

where A is area included by the contours of the anomaly. Such an estimate is of small practical value unless the mass is close to the surface and the anomalous figure well defined. In the present case, however, it furnishes a practical minimum value for the mass; the volume not included in the estimate is probably less than a third more than the minimum.

GRAVITY EXPRESSION OF THE HATCHETIGBEE ANTICLINE*

E. V. McCOLLUM†

ABSTRACT

A reconnaissance gravity survey is presented of the Hatchetigbee Area of Southwestern Albama, which discloses two gravity minima associated with the Hatchetigbee Anticline and the neighboring Jackson Fault. A study of the gravity data, together with geologic and magnetic information, leads to the possibility that a salt ridge exists in the general Hatchetigbee Area, and that the gravity minima represent individual salt domes.

INTRODUCTION

The Hatchetigbee Anticline, which is located in Choctaw, Clarke, and Washington Counties, Alabama, is one of the principal known structural features of Southern Alabama. The presence of the Hatchetigbee structure was established in 1850.[1] During the latter half of the last century, additional surface geology was done from time to time, such work being largely devoted to the Jackson Fault and the area between the fault and the Hatchetigbee Anticline.

Salt springs and salt seeps have been known to exist in the area since the arrival of the first white settlers.[2] The brine from the salt springs, augmented by that obtained from dug wells, was used as a source of salt by the Confederates during the Civil War.

The Hatchetigbee Anticline was recognized as a possible trap for petroleum at an early date, the first test well on the structure having been drilled in 1884. The discovery of oil at Spindletop led to a drilling campaign in 1902–1904 in the general Hatchetigbee-Jackson Area near the known salt springs.

During the past forty years, the surface geology of the Hatchetigbee Anticline and the Jackson Fault and their possible relationship to each other have been further investigated. Additional test wells have been drilled that have added to the subsurface data which in general confirms the surface geology. It is understood that some core drill and

* Presented at the Denver meeting, April, 1942.

† Mott-Smith Corporation, Houston, Texas.

[1] D. R. Semmes, *Oil and Gas in Alabama*, Geological Survey of Alabama, Special Report No. 15, page 363 (1929).

[2] Jelks Barksdale, *Possible Salt Deposits in the Vicinity of the Jackson Fault, Alabama*. Geological Survey of Alabama, Circular No. 10 (1929).

seismograph information has been obtained in the area by private organizations, but such data has not been made available to the public.

A magnetic survey of Southwest Alabama[3] covered the area under discussion, but neither the Hatchetigbee Anticline nor the associated Jackson Fault displayed any marked magnetic effect.

The Hatchetigbee—Jackson structure has a strike S 55° E over Hatchetigbee proper, but in T7N-R2E, the strike changes to a more southerly one, until finally at the southern end of the Jackson Fault, in T4N, R2E, the strike, as determined by surface geology, is west of south. The strike of the Hatchetigbee Anticline is oriented approximately 90° from the strike of the Appalachians of Central Alabama. This difference in strike has been puzzling to geologists, and has caused much conjecture regarding the origin of the Hatchetigbee Anticline.

THE GRAVITY SURVEY

A reconnaissance gravity survey of the Hatchetigbee-Jackson Area was made in the summer of 1940 with the thought that such data might possibly contribute to a better structural understanding of the area. A null type gravity-meter, the sensitivity of which was approximately 0.1 milligal per scale division, was used to establish the stations shown in Fig. 1. The gravity stations were tied to a system of gravity bench marks which are in turn tied into the pendulum stations established by the U. S. Coast and Geodetic Survey; thus, the station gravities are based on the world gravity network.

Latitude corrections were obtained from the well-known International Formula of 1930. Topographical and elevation corrections were made by applying a Bouguer type of correction which is proportional to sea-level elevation.

The corrected gravity values are contoured to an interval of one milligal. In order that the gravity contours may be more easily compared to geologic data, the Hatchetibee-Tallahatta contact and the surface trace of the Jackson Fault have been sketched on the gravity map.[4]

The dominant gravity features are two closed minima; one of which is located in and adjacent to T8N, R1E and 1W on the southeastern end of the Hatchetigbee Anticline, while the other falls in

[3] J. Brian Eby and E. G. Nicar, *Magnetic Investigations in Southwest Alabama.* Geological Survey of Alabama, Bulletin No. 43, p. 19. (1936).

[4] *Geologic Map of Alabama,* contained in Geological Survey of Alabama, Special Report No. 15 (1936).

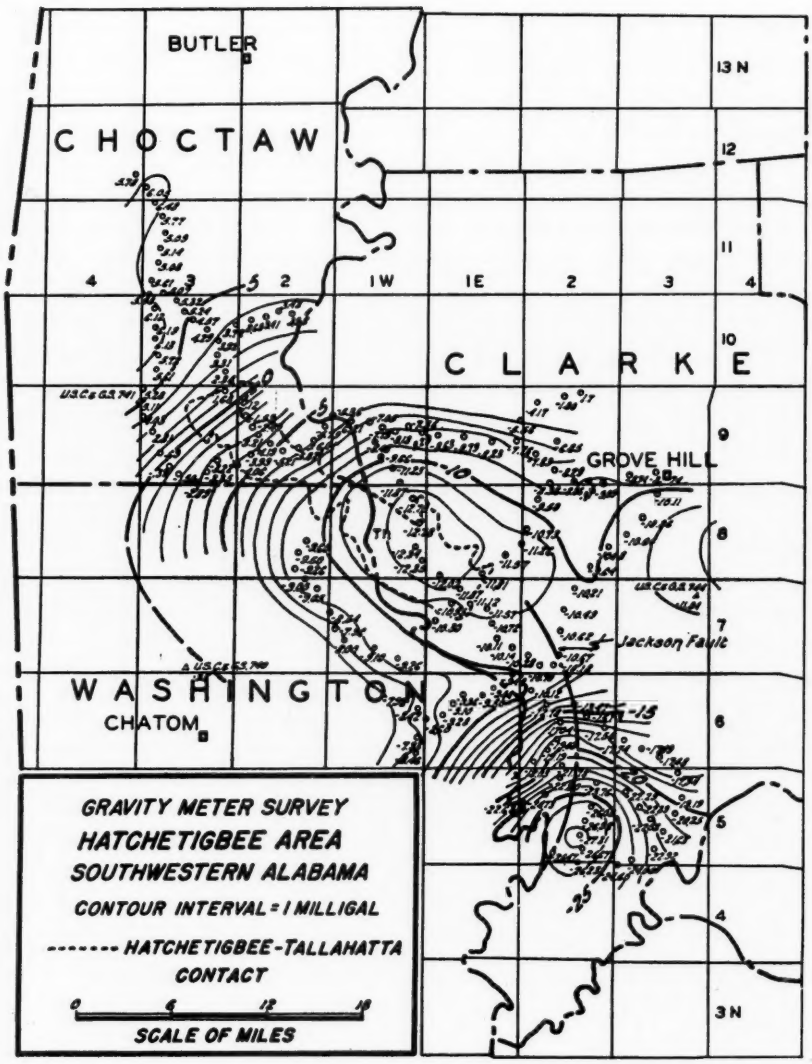


FIG. 1. Gravity map of the Hatchetigbee area of Southwestern Alabama. Contour interval is 1 milligal. The Hatchetigbee-Tallahatta contact is shown by a dashed line.

the southern part of T5N-R2E, near the Jackson Fault. Each of these anomalies is similar to gravity minima known to exist over salt domes of Louisiana and Texas. The Jackson Fault is not reflected in the gravity map in a manner anticipated for simple faulting.

Geologic Significance of the Gravity Data

The gravity minimum trend associated with the Hatchetigbee-Jackson structure may be interpreted as being caused by a buried salt ridge, with the separate gravity closures being indicative of salt spines or domes. The Jackson Fault may be subsidiary to the domes indicated by the gravity minima. Faults are often found in connection with salt domes, a good example of which is the fault that cuts across the Van Oil Field of Van Zandt County, Texas.[5]

A structural map, contoured on the top of the Selma Chalk, is shown in Fig. 2. In contouring this map, domes were assumed to coincide with the gravity minima of Fig. 1. The throw on the Jackson Fault was assumed to be about 500 feet, which is substantially the same as indicated by surface geology. Depth calculations were attempted from the gravity data, but due to inadequate density information in the general area, no positive quantitative conclusions were drawn. From a qualitative standpoint, the gravity data indicate that salt would exist at considerably shallower depths on the southern dome.

The possibility that geologic structures in the Hatchetigbee Area may be of salt dome type is based on the following criteria:

1. Gravity minima, similar in intensity and extent to those found in connection with salt domes in other parts of the Gulf Coast, exist in the area.

2. No appreciable magnetic anomalies were found over the Hatchetigbee Anticline or the Jackson Fault.

3. Subsurface information, based on the top of the Selma Chalk, may be contoured to show domal structures in approximately the same locations as the gravity minima.

Since the gravity survey described herein was made, the Union Producing Company's No. 1 Waite, located in Section 27, T8N, R1W, has confirmed the presence of salt in the area. Salt was topped at 12,291 feet and the well was abandoned at 12,399 feet in salt. The salt was reported to be interbedded with anhydrite, shaly lime, and siltstone; thus, very little piercement of salt through sedimentary formations occurs at this well location, up to depths of 12,300 feet. The subsurface information disclosed by the Union well is not inconsistent with the hypothesis that the Hatchetigbee Anticline may be underlain by a deep seated salt dome.

[5] Ralph Alexander Liddle, *Van Oil Field, Van Zandt County*, University of Texas Bulletin No. 3601 (1936).

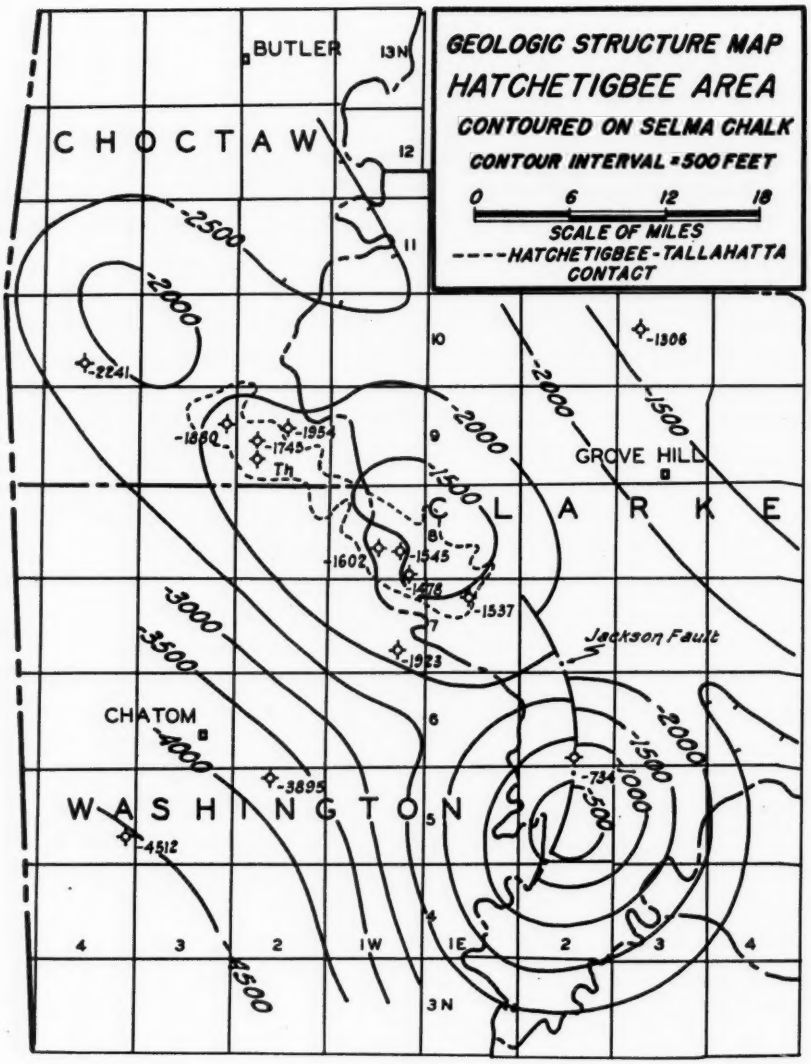


FIG. 2. Subsurface contour map of the Selma chalk. Contour interval is 500 feet. Contouring has been strongly influenced by the gravity observations.

NOTES ON EARTH TIDES*

WALTER D. LAMBERT†

ABSTRACT

Attention is called to the problem of the zero point for earth tides; this involves the so-called permanent tide or increase in the flattening of the earth. A suggestion is made for the use of existing tabulations for computing theoretical earth tides. Attention is also called to the effect of the varying distance of the tide-producing body and to the secondary effects of the oceanic tides. Finally the author requests to be kept informed of current developments.

The tidal variation of gravity and its accurate determination by means of modern gravimeters are of considerable interest from a purely scientific point of view. In this connection some remarks suggested by Dr. Adler's recent paper[1] may be in order.

1. The question of the datum, whether mean tide or lowest ebb, is not quite as simple as Dr. Adler's discussion makes it. We shall use mainly Dr. Adler's notation but without the subscripts, since we shall consider only one tide-producing body; the terms corresponding to the other are simply added in. We write by analogy with Dr. Adler's Eq. 5

$$\begin{aligned} C &= \tfrac{1}{3}K - K\cos^2\alpha \\ &= -\tfrac{2}{3}K(\tfrac{3}{2}\cos^2\alpha - \tfrac{1}{2}) \\ &= -\tfrac{2}{3}KP_2(\cos\alpha) \end{aligned} \qquad (1)$$

Here C is the vertical component of the tidal acceleration. K would be a constant if the orbit of the tide-producing body were circular (see hereinafter) and α is the zenith distance of the tide-producing body. The second and third forms of (1) go back to first principles and may be convenient in computation.

The mean value of $\cos^2\alpha$ is not $\frac{1}{2}$, as it would be if α ranged uniformly from 0° to 180°. In most places on the earth the tide-producing body never reaches the zenith or the nadir.

The value of $\cos\alpha$ is given by

$$\cos\alpha = \sin\phi\sin\delta + \cos\phi\cos\delta\cos t. \qquad (2)$$

Here ϕ and δ are respectively the latitude of the place of observation

* Manuscript received April 20, 1942.

† U. S. Coast and Geodetic Survey, Washington, D. C.

[1] Adler, Joseph L.: *Simplification of Tidal Corrections for Gravity Meter Surveys.* GEOPHYSICS, Vol. VII (Jan. 1942), pp. 35–44.

and the declination of the sun or moon. The hour angle is represented by t instead of Dr. Adler's $\theta'-\lambda$. If we have α or $\cos\alpha$, we can find at once the values of the zonal harmonic $P_2(\cos\alpha)\equiv\frac{3}{2}\cos^2\alpha-\frac{1}{2}$. Tables of zonal harmonics are included in many standard collections of tables.

The computation of the zenith distances from the same data as are here used is of great interest to navigators also, although they usually think in terms of the altitude, $90°-\alpha$. Many methods of graphical computation have been devised and many tables published. One of the most recent and extensive tables is published by the Hydrographic Office of the U. S. Navy as its Publication No. 214. The title is "Tables of Computed Altitudes and Azimuths." It fills eight volumes, which is not surprising in view of the fact that there are three arguments, each having a considerable range. There are similar smaller publications with wider tabular intervals or less extended range of the arguments, or both.

The range of these tables does not include hour angles for which the celestial body is below the horizon but this case is easily taken care of by reckoning from the nadir instead of from the zenith.

Let us put the expression for C in a form adapted to further development for purposes of harmonic analysis. By squaring the value of $\cos\alpha$ from (2) and by obvious transformations we find

$$C = K\left[-\tfrac{1}{6}-\tfrac{3}{2}\sin^2\phi\sin^2\delta+\tfrac{1}{2}\sin^2\phi+\tfrac{1}{2}\sin^2\delta\right] - K\left[\tfrac{1}{2}\sin 2\phi\sin 2\delta\cos t+\tfrac{1}{2}\cos^2\phi\cos^2\delta\cos 2t\right]. \qquad (3)$$

The terms in $\cos t$ and $\cos 2t$ have the mean value zero as t ranges from 0° to 360°; they represent the diurnal and semidiurnal portions of the tide.

The remaining terms within the square brackets

$$-\tfrac{1}{6}-\tfrac{3}{2}\sin^2\phi\sin^2\delta+\tfrac{1}{2}\sin^2\phi+\tfrac{1}{2}\sin^2\delta$$

may be written

$$-\tfrac{2}{3}(\tfrac{3}{2}\sin^2\phi-\tfrac{1}{2})(\tfrac{3}{2}\sin^2\delta-\tfrac{1}{2}).$$

It is not accidental that the factors $\frac{3}{2}\sin^2\phi-\frac{1}{2}$ and $\frac{3}{2}\sin^2\delta-\frac{1}{2}$ have the form of zonal harmonics of the second degree. The factor $\frac{3}{2}\sin^2\phi-\frac{1}{2}$ is constant for a given place. The other factor, $\frac{3}{2}\sin^2\delta-\frac{1}{2}$ runs its course twice in a lunar month or in a year, except for the effect of changing distances of the tidal body, thus giving rise to a fortnightly or semiannual tidal constituent. But again the mean value is not zero.

Let l be longitude in orbit of the body reckoned from the node of the orbit with the celestial equator and let ω be the inclination of the orbit to the equator. Then

$$\sin \delta = \sin \omega \sin l, \quad \text{and}$$

$$\tfrac{3}{2} \sin^2 \delta - \tfrac{1}{2} = \tfrac{3}{4} \sin^2 \omega - \tfrac{1}{2} - \tfrac{3}{4} \sin^2 \omega \cos 2l.$$

The term in cos $2l$ has a mean value zero and gives the fortnightly or semiannual tidal constituent; the terms $\frac{3}{4} \sin^2 \omega - \frac{1}{2}$ give a constant or quasi-constant tidal effect.

This corresponds to a small permanent increase in the flattening of the earth due to the presence of the sun and moon in the neighborhood of the equator.[2]

For the sun $\omega = 23^\circ\ 27'$, the obliquity of the ecliptic, and the value of $\frac{3}{4} \sin^2 \omega - \frac{1}{2}$ is -0.381. For the moon ω is variable with a range of some 5° on either side of $23^\circ\ 27'$ in a period of about 19 years, thus giving rise to a small constituent with a 19-year period in the tidal acceleration and in mean sea level.

The quasi-constant term for latitude ϕ is then

$$\tfrac{2}{3} \times 0.381 K (\tfrac{3}{2} \sin^2 \phi - \tfrac{1}{2}), \qquad (4)$$

the factor 0.381 being merely a mean value in the case of the moon. This term (4) represents an upward acceleration at the equator and a downward one at the poles. The other terms in cos $2l$, cos $2t$ and cos t have zero for their mean value at any given place.

2. The distance of the moon or sun is variable and the tidal effect of this variation is large enough to be considered. The tidal acceleration varies inversely as the cube of the distance and since the eccentricity of the moon's orbit is 0.0549, the lunar tides at perigee are to those at apogee as $1/(1-0.0549)^3$ is to $1/(1+0.0549)^3$, or as 1.185 is to 0.852, a range of about 33 per cent of the mean. The various perturbations of the moon make the possible range of effect due to varying distance still greater.

The quantity tabulated in the American Ephemeris and Nautical Almanac is not the distance but the parallax (pages 147–152). The sine of the parallax varies inversely as the distance, so instead of the factor K computed for mean distance, we should use $K(\sin p/\sin p_m)^3$,

[2] See Darwin, G. H. *The Theory of the Figure of the Earth Carried to Second Order of Small Quantities*, Scientific Papers, Vol. III, p. 114. The memoir originally appeared in the Monthly Notices of the Royal Astronomical Society, Vol. 60 (1900), pp. 82–124.

where p is the parallax at the given time and p_m is the mean parallax, or 57′ 02.″70. (American Ephemeris, p. xviii.)

The effect due to the variability of the sun's distance is smaller both absolutely and relatively, since the whole solar effect is smaller and the eccentricity of the earth's orbit is less than one-third that of the moon's orbit, 0.0167 against 0.0549. It is taken into account, if so desired, in the same way as for the moon. The American Ephemeris and Nautical Almanac gives both the distance (radius vector) and the solar parallax on opposite pages 1–17 (for 1942).

3. It would be interesting to have other determinations of the augmenting factor due to the elastic yielding of the earth, for which Dr. Adler uses 1.2, based on Wolf's[3] determination. Other preliminary determinations with gravimeters give even larger values for this augmenting factor. The theoretical value is $1+h-\frac{3}{2}k$, where h and k are dimensionless numbers that have been called Love's[4] numbers (but not by Love himself).

From observations of earth tides by means of deviations of the plumb line I estimate that k might be between 0.21 and 0.24 and that $h=2k$ approximately, the factor 2 being deduced from observation rather than from theory. For an incompressible earth of uniform density and rigidity we have from theory $h=\frac{5}{3}k$. This would give an augmenting factor of 1.11 or 1.12 rather than 1.20. In determining this factor by an inspection of the record there is a tendency to exaggerate its value. The safest way is to make a least-squares adjustment based on all hourly ordinates.

We must further allow for the fact that the record shows not only the direct or primary tidal effect due to the tidal forces and to the change in the shape of the earth caused directly by these forces but also the indirect or secondary effect due to the ocean tides. The ever-changing load of tidal water not only exerts a direct gravitational pull but also deforms the crust by its weight and thus raises or lowers the gravimeter, thereby altering the distance of the gravimeter from the center of the earth and consequently the recorded value of gravity.

These secondary effects are often very apparent in tidal observations on the direction of the vertical made with the horizontal pendulum or equivalent apparatus. At a station near a coast where the tide is large over a wide area of adjoining ocean these secondary effects

[3] Wolf, Alfred. GEOPHYSICS, Vol. V (1940), pp. 317–320; vol. VI (1941), pp. 81–83.

[4] Love, A. E. H. *Some Problems in Geodynamics.* Cambridge University Press, 1911.

may mask entirely the primary effects. At inland stations the secondary effects may be perceptible for a very considerable distance.

Our knowledge of the tides in the open sea is scanty and the mathematical difficulty of calculating these secondary effects is considerable. Accordingly only rough-and-ready calculations of these secondary effects on the directions of the plumb line have been made and the question of secondary effects on the vertical intensity has hardly been touched. Anyone, however, who attempts to interpret gravimeter observations should be prepared to encounter these effects.

These secondary effects may change not only the amplitude but the phase also. They may be different for different constituents of the tide.

As a first approximation it is probably sufficient to decompose the tide into its long-period, diurnal and semidiurnal constituents and to write, in the light of equations and the subsequent discussion

$$\begin{aligned} -C = {} & \tfrac{2}{3} f_0 K_0 \left(\frac{\sin p}{\sin p_m}\right)^3 (\tfrac{3}{2}\sin^2\phi - \tfrac{1}{2})(\tfrac{3}{2}\sin^2\delta - \tfrac{1}{2}) \\ & + f_1 K_0 \left(\frac{\sin p}{\sin p_m}\right)^3 \sin 2\phi \sin 2\delta \cos(t - \epsilon_1) \\ & + f_2 K_0 \left(\frac{\sin p}{\sin p_m}\right)^3 \cos^2\phi \cos^2\delta \cos(2t - \epsilon_2). \end{aligned} \tag{5}$$

Here f_0, f_1 and f_2 are respectively the factors for the long-period, the diurnal and the semidiurnal constituents; to the extent that they are affected by the ocean tides they would usually be all different. K_0 is the value of the coefficient for mean distance of the tide-producing body and for a rigid earth. For the moon

$$K_0 = \frac{3krM}{d^3} = 3g\left(\frac{r}{d}\right)^3 \cdot \frac{M}{E}.$$

Here k is the gravitation constant

r is the radius of the earth

d the mean distance to the moon; $r/d = 1/60.334 = 0.016574$

M the mass of the moon

g the acceleration of gravity $= 982.0$ cm/sec^2

E the mass of the earth; $M/E = 1/81.45$.

It is assumed that the phase disturbance for the long-period portion of the tide is zero, that is, that δ and p are taken for the instant of

observation, although this is merely an approximation. However, if we attempt to push our refinements beyond this point, it will be best to use the methods of the harmonic analysis as practiced for ocean tides.

A thoroughgoing investigation would then require the determination of five quantities, the factors f_0, f_1, f_2 and the phase disturbances ϵ_1 and ϵ_2. Because of difficulties with instrumental drift the determination of f_0 would probably have to be omitted. The phase disturbances, ϵ_1 and ϵ_2, may be of either sign. Bodily friction in the earth would give a positive sign but this effect is certainly small. Appreciable positive values of ϵ_1 and ϵ_2 must be due to other causes.

4. The writer of this note is Reporter for Earth Tides to the *International Association of Geodesy*. It has been his duty to prepare reports for submission to the triennial meetings of the Association.[5] He hopes that there will in time be opportunity for a further report and to that end he requests that he be kept informed of current developments. Separates of articles will be welcome and written communications will be kept confidential as long as may be desired.

[5] Lambert, Walter D., *Report on Earth Tides, 1936–38, U. S. Coast and Geodetic Survey Special Publication No. 223*. Washington, Government Printing Office, 1940. Previous reports were published by the Association internationale de Géodésie with headquarters at Paris.

NOTE ON THE VARIATION FROM EQUATOR TO POLE OF THE EARTH'S GRAVITY*

SIGMUND HAMMER†

ABSTRACT

The various physical factors constituting the increase in the normal acceleration of gravity of the earth from equator to pole are analyzed mathematically. The magnitudes of the essential factors are (1) centripetal acceleration +3.39 gals, (2) decrease in distance from the center of the earth—the so-called "Free Air" effect+6.63 gals, and (3) mass-shape effect due to polar flattening −4.85 gals.

It is well known that the acceleration of gravity of the earth is greater at the pole than at the equator. However, the resolution of this variation into its various physical factors seems to be less well known. For this reason, it is believed that the following analysis may be of interest.

According to the 1930 International Formula,[1]

$$g = 978.049(1 + 0.0052884 \sin^2 \phi - 0.0000059 \sin^2 2\phi),$$

the normal value of the earth's gravity at sea level (more precisely on the 1924 International Ellipsoid of Reference) increases from equator to pole by +5.17 gals. This variation is caused essentially by two factors:

1. Centripetal acceleration due to the rotation of the earth on its axis and

2. Changes in gravitational attraction because of the spheroidal shape of the earth.

The magnitude of the first factor can be calculated directly. It is

$$\Delta g_1 = \omega^2 a = +3.39 \text{ gals}$$

where $\omega = 2\pi/86{,}164 = 0.00007292$ is the angular velocity of rotation of the earth in radians per second and $a = 6.378 \times 10^8$ is the equatorial radius of the earth in centimeters.[2]

The magnitude of the second factor is less simple to evaluate. One method is to apply Clairaut's Theorem in the normal gravity formula.

* Manuscript received August 8, 1942.

† Gulf Research & Development Co., Pittsburgh, Pa.

[1] G. Cassinis, "*Tables des Valeurs de la Pesanteur Normale Internationale*" Bulletin Géodésique No. 32, Oct.–Nov.–Dec., 1931, pp. 313–326. L. L. Nettleton, "*Geophysical Prospecting for Oil*," McGraw-Hill, 1940, p. 18 and pp. 137–143.

[2] 86,164 is the number of mean solar seconds in one sidereal day.

Replacing the numerical coefficients in the normal gravity formula by symbols we have

$$g = g_e(1 + \beta \sin^2 \phi - \beta' \sin^2 2\phi).$$

This gives the increase in gravity from equator to pole

$$g_p - g_e = \beta g_e.$$

But by Clairaut's Theorem[3] (to second order accuracy)

$$\beta = (5/2)m - \alpha + \cdots$$

where $m = \omega^2 a/g_e$ is the ratio of the centripetal acceleration to the earth's gravity at the equator and $\alpha = (a-b)/a = 1/297$ is the flattening of the earth (b=polar radius). Hence

$$g_p - g_e = \tfrac{5}{2}\omega^2 a - \alpha g_e + \cdots \equiv \Delta g_1 + \tfrac{3}{2}\omega^2 a - \alpha g_e + \cdots .$$

Therefore, (using $g_e = 978$ and $\alpha = 1/297$) factor (2) is approximately

$$\Delta g_2 \equiv \tfrac{3}{2}\omega^2 a - \alpha g_e + \cdots = +1.79 \text{ gals.}$$

The sum of Δg_1 and Δg_2 as calculated above (5.18 gals) does not check exactly with the difference (5.17 gals) from the normal gravity formula, but the discrepancy arises from neglect of fourth order terms in Clairaut's Theorem. The more precise calculation gives $\Delta g_1 = 3.392$ and $\Delta g_2 = 1.780$ in excellent agreement.

This method of calculating Δg_2 is not completely satisfactory as it gives no clear picture of the physical elements involved. A second method of calculating this factor will now be given which does this.

From MacCullagh's Theorem[4] the Newtonian potential V at a point P external to any finite body is

$$V = \frac{\gamma M}{r} + \frac{\gamma(A + B + C - 3I)}{2r^3} + \cdots$$

where γ = gravitational constant

r = distance from center of gravity (O) of the body to the point P

[3] F. R. Helmert "*Höhere Geodäsie*," Teubner, Leipzig, 1884, Vol. II, pp. 75–78.

A. S. Ramsey "*An Introduction to the Theory of Newtonian Attraction*," University Press, Cambridge, 1940. pp. 150–152.

National Research Council, "*Physics of the Earth—II, The Figure of the Earth*," Washington, D. C., 1931, pp. 134–136.

[4] E. J. Routh, "*A Treatise on Analytical Statics*," University Press, Cambridge. Vol. II, 2nd ed., 1922, pp. 66–67. Ramsey, *op. cit.*, p. 87.

M = mass of the body

A, B, C = moments of inertia about any three rectangular axes through the point O

I = moment of inertia about the line OP.

If the shape and mass distribution in the body are nearly spherical (which is the case with the earth) the series converges rapidly. From this equation the gravitational attraction F in the direction PO is

$$F = \frac{dV}{dr} = \frac{\gamma M}{r^2} + \frac{3\gamma(A + B + C - 3I)}{2r^4} + \cdots .$$

Assuming for the earth that the two equatorial moments A and B are equal, we have at the equator $I = A$ and $r = a$ and at the pole $I = C$ and $r = b$. Hence the change in the gravitational attraction is

$$F_p - F_e \equiv \Delta g_2 = \gamma M\left(\frac{1}{b^2} - \frac{1}{a^2}\right) - 3\gamma\,(C - A)\left(\frac{1}{b^4} + \frac{1}{2a^4}\right) + \cdots .$$

The first right hand term represents the increase in attraction from equator to pole due to decrease in distance from the center of the earth —the "Free Air" effect—and consequently the second term represents the decrease in attraction from equator to pole due to the flattened shape of the earth.

To evaluate this expression it is convenient to make use of the relation $C - A = JMa^2$ and eliminate a in terms of α and b to get

$$\Delta g_2 = \frac{\gamma M}{b^2}(2\alpha - \alpha^2) - \frac{9}{2}\frac{\gamma M}{b^2}J(1 + \tfrac{2}{3}\alpha + \cdots).$$

Now the mass of the earth[5] is 5.976×10^{27} gm and $\gamma = 6.670 \times 10^{-8}$ from which[6] $\gamma M = 3.986 \times 10^{20}$, and with $b = 6.357 \times 10^{8}$ we get $\gamma M/b^2 = 986$. Furthermore[7]

$$J = \tfrac{2}{3}(\alpha - \tfrac{1}{2}m + \cdots) = 0.001091.$$

[5] "*Handbook of Physical Constants*," Geological Society of America Special Papers No. 36, 1942, p. 104.

[6] The magnitude of γM can be obtained to a high accuracy directly in terms of geodetic quantities by the relation $\gamma M = a^2 g_e(1 + \beta - m + \cdots)$, which is found in Helmert, *op. cit.*, p. 90. It is probable that the value of M quoted above was derived in some such manner.

[7] Helmert, *op. cit.*, pp. 72 and 79. The value of J can also be obtained from astronomical data or by integration for any assumed density variation in the earth. See Ref. 3 National Research Council, pp. 143–148, and Helmert, pp. 473–492.

With these values we get the approximate final result

$$\Delta g_2 = +6.63 - 4.85 = +1.78 \text{ gals.}$$

Summarizing, the change in gravity from equator to pole on the earth consists essentially of three factors

1. Centripetal acceleration	+3.39 gals.
2. Free air effect	+6.63 gals.
3. Mass-shape factor	−4.85 gals.
Total	+5.17 gals.

The writer wishes to express his appreciation to Mr. W. D. Lambert, Chief of Section of Gravity and Astronomy, U.S.C. & G.S., for friendly discussions which led to this analysis.

REVIEWS

Seismic Effects of Quarry Blasting. J. R. Thoenen and S. L. Windes. Bureau of Mines Bulletin No. 442.

Damage From Air Blast. Progress Report I. S. L. Windes. Bureau of Mines Report of Investigations No. 3622.

Design and Calibration of Air Blast Meters. A. T. Ireland. Bureau of Mines Technical Paper No. 635.

Bulletin No. 442 summarizes the results of investigations performed by the Bureau of Mines since 1930 relative to damage to buildings from quarry blasts, a study which was undertaken to supply basic data in settlement of damage claims.

The question of damage to property arising from shots in seismic exploration is closely related to this subject and some useful information in this respect can be gained from the bulletin. In particular, tests indicate that for distances less than a critical magnitude, surface energy from shots increases rapidly with decreasing distance, while for increasing distances beyond the critical magnitude the energy diminishes but slightly. Therefore the distance between shot hole and vulnerable property should in general be made to exceed the critical distance, which was observed to be about 400 feet, though in the reviewer's observation this distance is subject to variation depending on the nature of the ground.

The bulletin treats property damage only to the extent of injury to plaster, for which convenient tables relating to charge size and travel distance are supplied (pp. 65–67). The seismic exploration profession would be greatly benefited by an equally detailed investigation directed toward establishing working rules for handling of claims for alleged water well damage.

It is stated that the modified Mercalli scale for earthquake intensity was found to be in contradiction to the observations of vibrations from quarry blasting and was accordingly set aside. A reconciliation between the two has therefore yet to be deduced.

Report of Investigations No. 3622 and *Technical Paper No. 635*, which are more of the nature of progress reports, may be of interest to the geophysical profession in connection with those rare cases where damage is alleged due to the firing of a charge in air, either for blastphone, or accidentally.

The "General Summary" and "Conclusions" of *Bulletin No. 442* are herewith quoted in full.

"General Summary.

This study is based upon data collected from records of several hundred tests conducted at 28 stone quarries situated in 11 Southern and Eastern States, in a limestone mine, and in 20 residential structures of various types.

The tests covered the detonation of explosive charges in regular quarry practice ranging in weight from 1.5 to 42,000 pounds. Distances between shot point and seismometer stations ranged from 100 feet to 2 miles. Transmitting mediums through which the seismic waves were propagated ranged from granites through limestones, shales, and clays to unconsolidated sand and gravel beds.

Amplitudes of ground displac ment as recorded ranged from 0.0001 to 0.06 inch and similar movements in structures, from 0.0001 to 0.01 inch for quarry blasts, and up to 0.3± inch for mechanical vibrations. Frequencies of the seismic waves ranged

from 3 to 80 cycles per second and the duration of individual vibrations from 0.1 to 8 seconds.

"*Conclusions.*

1. Seismic vibrations emanating from quarry blasting, in which the size of the shots and the distances from the shot to structure are not abnormal compared to customary quarry practice, produce no greater displacements of ground and residential structures than those produced by normal living activities within the structure or ordinary traffic conditions outside.

2. The magnitude of seismic displacement caused by quarry blasts can be predicted accurately enough for practical purposes if the weight of the explosive charge and the distance between shot point and structure are known.

3. Unconsolidated or abnormally thick overburden causes greater displacement at lower frequency than solid rock at equal distances and for equal weights of explosive charge.

4. Ground and structural displacement ranged from 0.0001 to 0.06 inch for quarry shots ranging in weight of explosive charge from 4 pounds at a distance of 185 feet to 15,400 pounds at 600 feet.

5. Buildings of one, two, or three stories can be vibrated in definite modes; their resonant frequencies and damping can be evaluated; hence their susceptibility to vibration can be determined.

6. Vibration of a residential structure at resonance does not in itself cause damage because of the restraining effect of damping inherent in the building.

7. Within the range of the tests made in this investigation, an acceleration equal to gravity ($g = 32.2$ ft. per sec^2) is a practical index of damage.

8. Customary vibrational disturbances from quarry blasting result in displacements and frequencies that represent accelerations of about 0.01 of gravity.

9. In tests carried to the damage point, damage occurred only when the acceleration nearly equaled or exceeded gravity.

10. The seismic vibration necessary to damage residential structures of the type tested in this study is much greater than that from ordinary quarry blasting."

M. B. WIDESS

PATENTS*

ELECTRICAL PROSPECTING

U.S. No. 2,291,596. G. E. White. Iss. 7/28/42. App. 9/27/39. Assign. Standard Oil Development Co.

Geophysical Prospecting. An electrical transient method of prospecting in which the current electrodes are energized by a d-c pulse of short duration obtained by discharging a condenser.

U.S. No. 2,293,024. P. W. Klipsch. Iss. 8/11/42. App. 2/5/40. Assign. E. E. Rosaire.

Method of Electrical Prospecting. A four electrode a-c method of electrical prospecting in which the frequency or station spacing are varied over a range through which the mutual impedance vs. frequency curve has the maximum negative slope.

* Abstracts by O. F. Ritzmann, Gulf Research & Development Co.

U.S. No. 2,294,395. K. H. Evjen. Iss. 9/1/42. App. 12/20/39. Assign. Nordel Corp.

Method and Apparatus for Making Geological Explorations. A four electrode square wave type of electrical prospecting apparatus using a double commutator and which is made direct reading by taking a portion of the earth current, interrupting it, passing it through a transformer, rectifying it and supplying it to the potentiometer which is used to balance the earth potential.

GEOCHEMICAL PROSPECTING

U.S. No. 2,292,300. R. O. Smith. Iss. 8/4/42. App. 7/10/40.

Photochemical Exploration Method. A method of soil analysis by leaching samples with pure water, decanting the solution, adding silver nitrate solution and exposing to ultraviolet light for a measured time and observing the color change produced.

U.S. No. 2,294,425. R. T. Sanderson. Iss. 9/1/42. App. 5/22/40. Assign. Stanolind Oil and Gas Co.

Geomicrobiological Prospecting. A method of soil analysis prospecting in which samples are examined for hydrocarbophagic and hydrocarbogenic bacteria and the results used to correct geochemical surveys, or in which cultures of these bacteria are placed in contact with soil or soil gas to determine directly the presence of hydrocarbons.

GRAVIMETRIC PROSPECTING

U.S. No. 2,290,354. R. H. Ray. Iss. 7/21/42. App. 2/3/39. Assign. Stanolind Oil and Gas Co.

Geophysical Instrument Mounting. A mounting for safely carrying a gravimeter in a truck and provided with means for lowering the instrument onto a tripod without removing it from the truck.

U.S. No. 2,290,740. D. H. Clewell. Iss. 7/21/42. App. 5/24/40. Assign. Socony-Vacuum Oil Co.

Gravity Meter. A null reading gravity meter of the unbalanced horizontal beam type in which null adjustment is accomplished by a secondary spring connected to an intermediate point on the main spring so that the tension in the secondary spring increases the tension in one part of the main spring and decreases it in the other part.

U.S. No. 2,291,628. G. A. Ising. Iss. 8/4/42. App. 2/23/38 and 2/24/37.

Apparatus for Relative Gravity Measurements. A gravimeter having a moving system with a horizontal axis and whose unbalance is compensated by electrostatic attraction between part of the moving system and a stationary charged plate.

U.S. No. 2,293,437. L. J. B. La Coste and A. Romberg. Iss. 8/18/42. App. 3/19/41.

Force Measuring Device. A gravity meter of the Galitzin unbalanced beam type using one or more zero length springs to support the moving system.

U.S. No. 2,294,201. T. B. Pepper. Iss. 8/25/42. App. 7/17/39. Assign. Gulf Research & Development Co.

Apparatus for Submarine Geophysical Prospecting. A casing for an underwater gravimeter to be lowered to the floor of a body of water, rough leveling being accomplished by the action of gravity through gimbals and final leveling by automatically controlled motors.

U.S. No. 2,294,202. T. B. Pepper. Iss. 8/25/42. App. 9/24/41. Assign. Gulf Research & Development Co.

Apparatus for Submarine Geophysical Prospecting. An underwater gravimeter casing having a concave base and a suction pump for reducing the pressure under the concave base so that the casing is held tightly to the bottom by suction.

U.S. No. 2,295,026. H. Brown and J. H. Martin. Iss. 9/8/42. App. 6/5/39.

Force Measuring Device. A gravimeter having a mass suspended by three fibers not in the same plane, the fibers being in torsion and twisted so that the system approaches instability.

U.S. No. 2,296,330. L. W. Blau. Iss. 9/22/42. App. 8/29/35 and 2/3/38. Assign. Standard Oil Development Co.

Gravity Balance. A balanced beam type gravity meter in which magnification is obtained by the use of a mirror mounted on an auxiliary horizontal pendulum fastened to the beam.

SEISMOGRAPH PROSPECTING

U.S. No. 2,290,773. E. M. Shook and R. W. Olson. Iss. 7/21/42. App. 10/23/40. Assign. Socony-Vacuum Oil Co.

Electric Seismograph. A method of using radio for communication and also for recording shot moment and up-hole time breaks without interference by using two receiving channels in parallel, one normal for speech, and the other containing a tube biased to cut off so that it passes only high amplitude signals.

U.S. No. 2,291,779. W. R. Welty. Iss. 8/4/42. App. 5/13/40. Assign. Olive S. Petty.

Geophysical Apparatus and Method. A method of seismograph prospecting using geophones which convert earth vibrations into a modulated carrier wave, using a single cable inductively coupled to all the detectors, then filtering to identify the various geophone signals, and detecting, amplifying and recording.

U.S. No. 2,293,288. C. W. Gadd. Iss. 8/18/42. App. 5/29/40. Assign. General Motors Corp.

Vibration Indicator. An optically recording vibrometer whose seismograph mass is connected to a counterbalance by means of springs so that the zero position of the mass is unaffected by the orientation of the instrument.

U.S. No. 2,294,627. J. O. Parr, Jr. Iss. 9/1/42. App. 3/31/41. Assign. Olive S. Petty.

Seismic Surveying. A method of eliminating a-c pickup in seismograph channels by shunting a potentiometer across the amplifier input transformer primary and connect-

ing the potentiometer slider to ground through a resistance-capacity phase shifting device.

U.S. No. 2,296,754. A. Wolf and L. G. Cowles. Iss. 9/22/42. App. 4/29/39. Assign. The Texas Company.

Astatic Electromagnetic Vibration Detector. A seismograph detector made up of two units whose pick up coils are connected so that their emf's due to vibrations are added and the voltages induced by the external magnetic fields are cancelled.

U.S. No. 2,297,319. J. O. Parr, Jr. Iss. 9/29/42. App. 6/18/40. Assign. Olive S. Petty.

Seismic Circuits. An A. V. C. system for seismograph amplifiers in which the A. V. C tube changes the bias of the amplifier tubes and also at the same time changes its own bias so as to inhibit subsequent action.

U.S. No. 2,298,020. J. O. Parr, Jr. Iss. 10/6/42. App. 4/5/40. Assign. Olive S. Petty.

Seismic Surveying. A variable air gap reluctance type seismic detector having a suspended mass of very long period and small air gap, so that after the very first impulse mechanical contact between the mass and the magnet pushes the mass away some distance enlarging the air gap and reducing the sensitivity, recovery being slow enough to restore the normal sensitivity toward the end of the record.

WELL LOGGING AND SURVEYING

U.S. No. 2,289,687. R. W. Stuart. Iss. 7/14/42. App. 2/14/41. Assign. Stanolind Oil and Gas Co.

Method and Apparatus for Logging Wells. A method of mud logging in rotary drilling which measures and records the electrical conductivity and the hydrogen ion concentration of the fluid along with the gas and oil content.

U.S. No. 2,290,408. W. J. Crites. Iss. 7/21/42. App. 2/21/41. Assign. Phillips Petroleum Co.

Exploration of Boreholes. A method of logging while drilling by recording the difference between the volume of mud pumped in and the volume of mud returned to the mud pit.

U.S. No. 2,291,692. R. T. Cloud. Iss. 8/4/42. App. 6/2/38. Assign. Stanolind Oil and Gas Co.

Magnetic Logging. A method of magnetic well logging in which the formations are magnetized either by the earth's field and earth currents, or an energizing coil, and the magnetization is determined from the emf generated in a pick up coil rotated at a constant speed.

U.S. No. 2,295,738. J. R. Gillbergh. Iss. 9/15/42. App. 12/16/40.

Method and Means for Determining the Points of Ingress of Well Fluid. Apparatus for electrically testing the well fluid at a number of points in a well, and automatically making a repeated succession of readings at these points so as to show the change in character of the fluid with time.

U.S. No. 2,296,176. J. Neufeld. Iss. 9/15/42. App. 3/9/40. Assign. Well Surveys, Inc.

Well Survey Method and Apparatus. A method of natural or artificially induced gamma ray well logging in which two differently shielded ionization chambers are used and the quotient of their amplified outputs used to indicate the spectral distribution of the gamma rays.

U.S. No. 2,296,852. W. L. Horner. Iss. 9/29/42. App. 1/3/38. Assign. Core Laboratories Inc.

Earth Exploration. A method of determining the productivity of formations by taking cores, bringing them to the surface, distilling off water and oil, determining the pore space by forcing an incompressible liquid into the sample, and from the ratios of these quantities predicting the productivity.

U.S. No. 2,296,981. M. E. Chun. Iss. 9/29/42. App. 9/24/40. Assign. Lane-Wells Co.

Method and Apparatus for Determining the Point of Water Entry into Oil Wells. Running a long wire or rod into the well over the region to be investigated, later removing it and observing the electrochemical action on the wire caused by either externally applied potential or by local action.

U.S. No. 2,296,996. P. Jones. Iss. 9/29/42. App. 8/3/40.

Directional Drift Recorder. A photographic recording drift and direction indicator using a fixed light source, a mirror fastened to a compass needle to give direction, and a second mirror floating on mercury to give the deviation from vertical.

U.S. No. 2,297,568. E. G. Leonardon. Iss. 9/29/42. App. 2/25/39. Assign. Schlumberger Well Surveying Corp.

Spontaneous Potential by Induction. A method of measuring spontaneous currents flowing between formations transversed by a well by running in the hole a magnetizable core and a coil or a pair of rotating coils and measuring the induced voltage.

U.S. No. 2,297,754. G. H. Ennis. Iss. 10/6/42. App. 12/28/36. Assign. One-half to Robert V. Funk.

Method of Locating Strata in Wells and Electrode Apparatus Therefor. An electric well logging method using two surface electrodes and one or two electrodes in the well, the latter arranged to be mechanically centered in the hole or adjacent to one side in a particular azimuth.

U.S. No. 2,297,939. J. G. Campbell. Iss. 10/6/42. App. 10/9/40. Assign. Ralph H. Fash, trustee.

Method of Detecting the Penetration of an Oil-Bearing Horizon. Determining the oil content of the solid residues of drilling fluid before and after circulation by evaporating the fluid, leaching the solid residue with an oil solvent, observing the ultraviolet fluorescence of the solution and noting any increase by comparison with prepared standards.

U.S. No. 2,298,794. L. G. Howell. Iss. 10/13/42. App. 6/23/41. Assign. Standard Oil Development Co.

Well Logging. A gamma ray well logging device using two Geiger Müller counters whose outputs are amplified and the impulses impressed 180 deg out of phase respec-

tively on a single conductor cable, the impulses being separated at the surface by two thyratron tubes connected to be fired respectively by the two oppositely directed impulses.

MISCELLANEOUS

U.S. No. 2,291,713. G. Hefley. Iss. 8/4/42. App. 2/14/40. Assign. Olive S. Petty.

Galvanometer. A string galvanometer having a heart shaped leaf spring for producing tension, the spring being so shaped that increasing deflection increases its lever arm resulting in a low force constant.

U.S. No. 2,292,838. P. H. Jones. Iss. 8/11/42. App. 12/6/38. Assign. Union Oil Co.

Method and Apparatus for Imparting Directional Magnetic Properties to Core Samples. A method of facilitating core orientation by drilling a small hole in the formation to be cored, injecting into this hole cement containing magnetic particles in suspension, allowing cement to set and then coring.

U.S. No. 2,293,488. G. S. Bays. Iss. 8/18/42. App. 4/6/38. Assign. Stanolind Oil and Gas Co.

Apparatus for Determining Permeability. Apparatus for measuring the porosity, bulk volume, and permeability of dry well cores by enclosing the sample in a chamber and measuring the time required to force a pre-determined quantity of liquid into the sample by hydrostatic pressure.

U.S. No. 2,294,320. O. F. Ritzmann. Iss. 8/25/42. App. 6/6/40. Assign. Gulf Research & Development Co.

Oscillograph. An oscillograph having a band pass response characteristic obtained by using two vibrators of different frequency and optically recording the difference in their instantaneous deflections.

U.S. No. 2,296,366. W. D. Mounce. Iss. 9/22/42. App. 12/29/41. Assign. Standard Oil Development Co.

Borehole Tool. A device for locating casing seat or other non-magnetic casing structure in a well by using a catch controlled through a mechanism which is set by the attraction of a permanent magnet for magnetic material.

U.S. No. 2,297,828. W. R. Flatford. Iss. 10/6/42. App. 5/12/41. Assign. Phillips Petroleum Co.

Coupling. A coupling for attaching a well logging cable to an electrode system, the strain being carried by an insulating member in compression and well fluid excluded by packing glands.

PUBLICATIONS RECEIVED

The *SOCIETY* has exchange agreements with a number of journals concerned directly or indirectly with geophysical exploration, as a result of which we receive these journals in exchange for GEOPHYSICS. The Society is also in receipt from time to time of reprints of papers appearing in journals with which we do not maintain exchange agreements.

With this number of GEOPHYSICS a new department is being inaugurated, to be called *PUBLICATIONS RECEIVED*. In it will be listed publications which have been received since the previous issue, with a listing of papers of particular interest to geophysicists. All material received is filed by the Business Manager, Box 1925, Washington, D. C., and is available for loan to any member of the Society upon request.

The following material is at present in the files of the Society:

American Journal of Science, Vol. 240, No. 8 (New Haven, August, 1942), pp. 529–600.

Annotated Bibliography of Economic Geology for 1936, Vol. IX, No. 2 (Lancaster, July, 1937), pp. 1–433.

"*A Proposito de los Generos Plohophorus, Nopachthus y Panochthus*" (*2a Parte*), by Alfredo Castellanos. *Pubs. del Inst. de Fisio. y Geol.*, VIII (Santa Fe, Argentina, 1940), pp. 279–418. In Spanish.

Beiträge zur Angewandten Geophysik, Vol. 6, 1938; Vol. 7, 1939; Vol. 8, 1940; Vol. 9, No. 1, 1941 (Leipzig). In German, with English summaries.

Bulletin of the Academy of Science of the Union of Socialist Soviet Republics (Geographic and Geophysic Series), No. 4, pp. 483–608, 1937; Nos. 1, 2–3, pp. 1–302, 1938; Nos. 1–6, pp. 1–722, 1939; No. 1, pp. 1–152, 1940 (Moscow). In Russian, with English summaries.

Bulletin of the American Association of Petroleum Geolgoists, Vol. 20, 1936; Vol. 21, Nos. 1–8, 11–12, 1937; Vol. 22, 1938; Vol. 23, 1939; Vol. 24, 1940; Vol. 25, 1941; Vol. 26, Nos. 1–11, 1942 (Tulsa).

"*Cronica Bibliografica Mineralogia y Mineria, Geologia, Petrografia, Geografia, Paleontologia,*" by Alfredo Castellanos and Pierina Pasotti. *Pubs. del Inst. de Fisio. y.Geol.*, B-1940 (Rosario, Argentina, 1940), pp. 47–112.

Economic Geology, Vol. XXXVII, Nos. 2–6 (Lancaster, March–October, 1942), pp. 87–530.

"Electrometrical Work by Equipotential Method in Ural Mountains (USSR)," by P. F. Rodionov and J. M. Pruschinsky. *Trans. Cent. Geol. and Prosp. Inst.*, No. 54 (Moscow, 1936), 120 pp. In Russian, with English summary.

Experiment Station Soil Mechanics Bulletin, The, No. 14. Pub. of Soil Mechanics Res. Center, U. S. Waterways Exp. Sta., U. S. Army Corps of Engrs., War Dept. (Vicksburg, Miss., Feb. 20, 1942), 36 pp.

Exploration Geophysics, by J. J. Jakosky. (Times-Mirror Press, Los Angeles, 1940), 786 pp.

Explosives Engineer, The, Vol. 20, Nos. 4–8 (Hercules Powder Co., Wilmington, April–July, 1942), pp. 94–216.

Geofisica Pura e Applicata, Vol. I, No. 1 (Messina, 1939), pp. 1–72. In Italian.

"German-English Vocabulary of Soil Terms," compiled by H. B. Edwards. *The Experiment Station Soil Mechanics Bulletin*, No. 15 (Vicksburg, Miss., July 10, 1942), 49 pp.

Grundlagen und Methoden der Periodenforschung, by Dr. Karl Stumpff. (Julius Springer, Berlin, March, 1937), 332 pp.

Independent Petroleum Association of America Monthly, The. Vol. X, No. 12 (April, 1940); Vol. XI (May, 1940–April, 1941); Vol. XII (May, 1941–April, 1942); Vol. XIII, Nos. 1–4 (May, 1942–August, 1942). Tulsa.

Journal of Applied Physics, Vol. X, No. 9 (September, 1939), pp. 597–666; Vol. XI, Nos. 4, 6 (April, June, 1940), pp. 231–300, 371–450; Vol. XII, Nos. 7, 12 (July, December, 1941), pp. 511–582, 823–890; Vol. XIII, Nos. 1–10 (January–October, 1942). Lancaster.

Journal of Scientific Instruments, The, Vol. VII, 1936; Vol. VIII, 1937; Vol. IX, 1938; Vol. X, 1939; Vol. XI, 1940; Vol. XII, 1941; Vol. XIII, Nos. 1–10, 1942 (Lancaster).

Journal of the Acoustical Society of America, The, Vol. 8, No. 3 (Lancaster, January, 1937), pp. 155–210.

Journal of the Institute of Petroleum, The (continuation of *The Journal of the Institution of Petroleum Technologists*), Vol. 25, Nos. 183–194 (1939); Vol. 26, Nos. 195–206 (1940); Vol. 27, Nos. 207–216 (1941); Vol. 28, Nos. 217–221 (January–May, 1942), pp. 1–81; 1A–221A. (Birmingham, England.)

Journal of the Institution of Petroleum Technologists, The (see above), Vol. 23, Nos. 159–170 (1937); Vol. 24, Nos. 171–172 (January, February, 1938), pp. 1–123, 1A–78A, Nos. 174–182 (April–December, 1938), pp. 181–711, 163A–542A. (Birmingham, England.)

"*L'alluvion du Rhone valaisan,*" by Maurice Lugeon and Nicolas Oulianoff. *Bul. des Labs. de Geol., Geog., Phys., Min. et Paleo. de l'Univ. de Lausanne*, No. 64. (Lausanne, 1939), 26 pp. In French.

"*La Mica en la Argentina,*" by Luciano R. Catalano. Pubs. del Inst. de Fisio. y Geol., X (Santa Fe, Argentina, 1940), 133 pp. In Spanish.

"*Lecture Notes on Practical Petroleum Geophysics,*" by Garrett Kemp. *Bul. A. & M. College of Texas*, No. 48, Vol. 11, No. 5 (College Station, May, 1940), 65 pp.

Materials of the Central Geological and Prospecting Institute. Geophysics Magazine I, 1935, 38 pp.; II, 1936, 64 pp.; III, 1937, 56 pp. (Moscow). In Russian, with English summaries.

"*Methods of Estimating Underground Oil Reserves,*" by V. Bilibin. Presented at the International Geological Congress, XVII Session, USSR, 1937 (Leningrad, 1936), 24 pp.

Oil Industry in Your State, The (mimeo.). Ind. Pet. Assn. America (Tulsa, 1941), 26 pp.

Petroleum, Vol. 1, Nos. 5, 6 (March, April, 1940), pp. 153–224; Vol. 2, Nos. 1–6 (May, October, 1940), pp. 1–216, No. 8 (December, 1940), pp. 253–288; Vol. 3, Nos. 1, 2 (January, February, 1941), pp. 1–58; Vol. 4 (May–December, 1941); Vol. 5, Nos. 1–5, (January–May, 1942), pp. 1–99; Nos. 7, 8 (July, August), pp. 111–146. (London).

Petroleum Technology in 1940 (Annual Reviews of Petroleum Technology, Vol. 6), 318 pp. (Birmingham, England).

Proceedings of the Cambridge Philosophical Society, Vol. 32, (1936), pp. 1–750; Vol. 33, (1937), pp. 1–594; Vol. 34 (1938), pp. 1–645; Vol. 35 (1939), pp. 1–663; Vol. 36 (1940), pp. 1–512; Vol. 37 (1941), pp. 1–445; Vol. 38, No. 1 (1942), pp. 1–128. Cambridge, England.

Result of Torsion Balance Survey of the Lead-Zinc Deposit in Shuikoushan, South

Hunan," by S. P. Lee and H. L. Chin. *Geophysical Memoirs*, No. 1, February, 1941.

Revista de Ciencias, No. 422 (December, 1937), 164 pp.; No. 423, (March, 1938), 145 pp.; No. 426 (December, 1938), pp. 481–646; No. 427 (March, 1939), pp. 1–123; No. 429 (September, 1939), pp. 289–464; No. 430 (December, 1939), pp. 435–769; No. 431 (March, 1940), pp. 1–228; No. 433 (September, 1940), pp. 541–821; No. 434 (December, 1940), pp. 817–977; Nos. 435–438 (March–December, 1941), pp. 1–694; No. 439 (March, 1942), pp. 1–156. Lima Peru. (Published in language of author.)

Revista Geomineria—Geologia e Geofisica Applicata, Vol. II, No. 1 (Milan, January, 1941), pp. 1–64.

Thermometric Method of Searching for Sulphide Ore Bodies, The by N. I. Sofronov. (Moscow, 1936). 51 pp. In Russian, with English summary.

Tulsa Geological Society Digest, Vol. X (Tulsa, 1942), 108 pp.

World Petroleum, Vol. 11, Nos. 5, 7–13 (1940); Vol. 12 (1941); Vol. 13, Nos. 1–9, 11, 12 (1942). New York.

The following three reprints have recently been received which will be of particular interest to those concerned with geophysical education, either as teachers, employers, or prospective students.

Integration of Geology, Physics and Chemistry for the Solution of Earth Problems. Report of Geophysics Education Committee of Mineral Industry Education Division, A.I.M.E. Technical Publication No. 1483, Class J, No. 16, and Class L, GEOPHYSICS, No. 88. Sherwin F. Kelly, Chairman.

Training of Physicists for Work in the Field of Applied Physics. J. C. Karcher. American Journal of Physics, Vol. 10, No. 4, pp. 185–188 (August 1942).

Are Mineral Industries Educators Rising to the National Emergency. Edward Steidle. *Mineral Industries*, Vol. 12, No. 1, (October 1942). State College, Pennsylvania.

Technical Publication No. 1483, which is the most recent report by the Geophysics Education Committee of the A.I.M.E., summarizes the four years of activity of this committee. It is concerned largely with the presentation of a curriculum recommended for preparation of a student for work as a professional geophysicist. The responsibility of the High Schools to offer better preparation for college technical courses is emphasized both in the text of the report and in the discussion. It is of interest to note in passing that ten of the sixteen members of the Committee are members of the Society of Exploration Geophysicists.

Dr. Karcher emphasizes the need for strong training in the fundamental sciences plus inculcation of the practical point of view (not necessarily practical skills in geophysics.)

Dean Steidle is concerned largely with the fact that the mineral industries side of education is inclined to get slighted when college budgets are prepared, and he asks why, if there are Schools of Arts and Sciences, of Engineering, and of Law, there should not be Schools of "Geotechnology," the latter being a coined word signifying the application of science and engineering to all those problems connected with the study of the earth and the discovery and utilization of its natural constituents.

The *Bulletin of the American Association of Petroleum Geologists*, Vol. 26, No. 11, (November 1942), pp. 1789–1794, contains a set of "Notes on Selective Service" by A. R. Denison which will be of interest to employers and to men of draft age.

CONTRIBUTORS

C. A. SWARTZ received the B.S. degree in 1927 and the Ph.D degree in 1931 from the California Institute of Technology. He was employed as research physicist by the Union Switch and Signal Company in 1931 and 1932, and since 1933 he has been employed as a geophysicist by the Gulf Research and Development Company in the seismograph interpretation department. Dr. Swartz is a member of the American Physical Society, Sigma Xi, and the Society of Exploration Geophysicists.

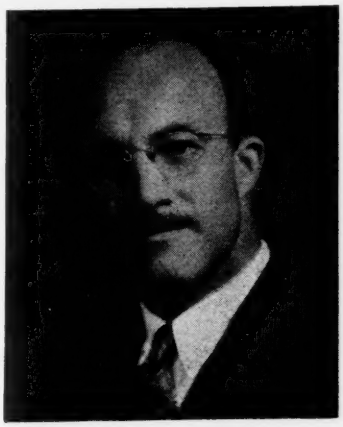
C. A. SWARTZ

L. E. DEACON

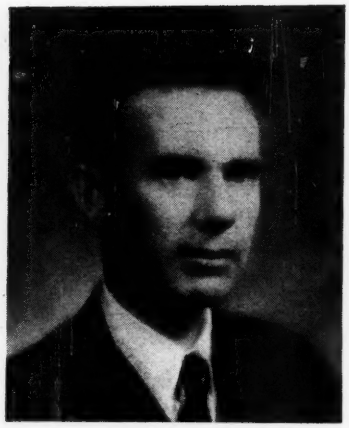
L. E. DEACON received his B. A. Degree in Physics from the University of Texas in 1933. He continued his studies in Mathematics and Physics and tutored in the Department of Physics until 1934, when he became associated with Shell Oil Co., Inc., by whom he is still employed. His work with Shell has been largely in the field of seismic interpretation.

Mr. Deacon is an associate member of Sigma Xi and a member of the Society of Exploration Geophysicists.

C. M. ENGLAND received his A.B. degree from Phillips University in 1926, and his M.S. degree in physics from the University of Oklahoma in 1928. He has been employed by the Geophysical Research Corporation since December, 1928. During the period 1936 to 1938 he was in charge of an experimental electrical crew. He is a member of the Society of Exploration Geophysicists.



C. M. ENGLAND



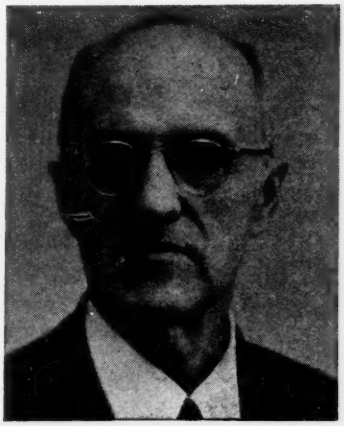
VIRGIL E. BARNES

VIRGIL E. BARNES received his B.S. and M.S. degrees in geology from the State College of Washington in 1925 and 1927, respectively, and his Ph.D. in geology from the University of Wisconsin in 1930. Field seasons during his graduate studies were spent on the Washington Geological Survey, Wisconsin Geological Survey, and with the Dominion Explorers Ltd., Canada. He was research fellow with the American Petroleum Institute for one year working on earth temperatures and oil field waters of north-central Texas. Following this he was with the Topographic Branch of the United States Geological Survey; and in 1935 became associated with the Bureau of Economic Geology, of the University of Texas, where he is now engaged in mineral investigations connected with the war effort. Dr. Barnes is a member of the Geological Society of America.

E. V. MCCOLLUM received his A.B. degree in 1925 and his M.S. degree in 1926, both from the University of Oklahoma. He was employed by the Marland Oil Company from June, 1926, until July, 1929, and by Continental Oil Company as Control Geophysicist from July, 1929, to May, 1939. Since May, 1939, he has been associated with the Mott-Smith Corporation as Chief Geophysicist. He is a member of the American Physical Society, the American Geophysical Union, the Seismological Society of America and the Society of Exploration Geophysicists.

E. V. MCCOLLUM

WALTER D. LAMBERT received the degrees of A.B. and A.M. from Harvard in 1900 and 1901. He then taught mathematics and astronomy and worked for the U. S. Coast and Geodetic Survey. In 1911 his present connection with the Survey began; it has been continuous to the present, except for nearly two years of service with the Corps of Engineers, U. S. Army, in World War I. Mr. Lambert is now Principal Mathematician and Chief of the Section of Gravity and Astronomy. He is a member of the American Association for the Advancement of Science, of the Seismological Society of America, and of the American Geophysical Union, having been Secretary and then Chairman of its Section of Geodesy. He is Vice President of the International Association of Geodesy and Reporter for Earth Tides to that organization.



WALTER D. LAMBERT

SIGMUND HAMMER

SIGMUND HAMMER received the A.B. degree from St. Olaf College, Northfield, Minnesota, in 1924 and was graduate student and Teaching Fellow in the Physics Department of the University of Minnesota from 1924 to 1929 where he received the Ph.D. degree. During this time he was occasionally employed as radium technician in the University Hospital and radio operator in a broadcasting station and on board ship. He has been in the Geophysics Department of the Gulf Research & Development Company, Pittsburgh, Pennsylvania, since 1929 where his principal duties have been: gravity interpretation, supervision of technical aspects of gravity field operations, studies of the gravitational field of the earth and geophysical applications of the statistical theory of errors. He is a member of the American Physical Society, American Geophysical Union, Physical Society of Pittsburgh (Secretary-Treasurer 1941–1942 and Vice-President 1942–), New York Academy of Sciences, Sigma Xi, and the Society of Exploration Geophysicists.

FREDERICK ROMBERG. A biography and photograph will be found in GEOPHYSICS, Vol. VI, no. 4, p. 461 (October 1941).

THE SOCIETY ROUND TABLE

ANNOUNCEMENT OF ANNUAL MEETING—1943

Present plans are to hold the usual annual meeting of the Society of Exploration Geophysicists concurrently with the meeting of the American Association of Petroleum Geologists in Fort Worth, Texas, on April 7, 8, and 9.

The following is a tentative schedule of the meeting:

Tuesday, April 6, Evening; Registration, Executive Committee Meeting

Wednesday, April 7,	Registration
9 A.M.	Annual Business Meeting
	Technical Session
P.M.	Technical Session
Evening	Joint Session with A.A.P.G. Research Committee
Thursday, April 8,	Joint Sessions with A.A.P.G.
A.M.	Presidential Addresses and Invited Addresses
P.M.	Invited Addresses
Evening	Popular Speaker and Smoker
Friday, April 9,	Joint Sessions with A.A.P.G.
A.M.	Symposium on Secondary Recovery
P.M.	Symposium on Favorable Areas for Wildcatting

The Program and Arrangements Committee has been appointed as follows:

Tulsa Area—Andrew Gilmour, Geophysical Research Corp., Box 2040, Tulsa, Oklahoma

Houston Area—W. M. Rust, Jr., Humble Oil & Refining Co., 2222 Shakespeare, Houston, Texas

Rocky Mountain Area—Dart Wantland, Colorado School of Mines, Golden, Colorado

Pacific Coast Area—H. W. Washburn, Consolidated Engineering Corp., 1255 East Green Street, Pasadena, California

Dallas-Fort Worth Area (and in charge of local arrangements)—John H. Wilson, Independent Exploration Co., White Settlement Road, Fort Worth, Texas

Atlantic Coast Area (General Chairman)—L. L. Nettleton, Gulf Research & Development Co., Box 2038, Pittsburgh, Pennsylvania

Since the principal source of papers for GEOPHYSICS is the Annual Meeting, all members who can possibly do so are urged to prepare papers for listing in the program, whether or not they expect to be able to present them in person at the meeting. If the time now scheduled for the presentation of papers is insufficient for the number of papers submitted, either a Friday morning technical session will be scheduled, or papers of a highly specialized nature may be scheduled to be read by title, as will papers for which the author is unable to be present.

If there is a possibility that you will be able to prepare a paper, get in touch with your local program committee member as soon as you can, and submit to him a tentative title. An attempt should be made to submit abstracts of papers by March 1.

The ballot reprinted below was mailed to all active members of the Society of Exploration Geophysicists on December 15, 1942. Active members who failed to receive ballots may secure them by notifying J. F. Gallie, Business Manager, P. O. Box 1925, Washington, D. C. *Only active members who have paid 1943 dues are eligible to vote.*

OFFICIAL BALLOT

FOR THE YEAR APRIL, 1943—APRIL, 1944

For the Election of Officers for the

SOCIETY OF EXPLORATION GEOPHYSICISTS

Before voting, please note the following extracts from the Society Constitution:
Article V-A—Officers

1. **The officers of the Society shall be a President, a Vice-President, a Secretary-Treasurer, and an Editor. These, together with the Past President, shall constitute the Executive Committee and managers of the Society. Officers shall be elected for a term of one year with the exception of the Editor, who shall be elected for a term of three years.***

2. **. . . Each member shall cast one vote for each officer to be elected and shall return his ballot to the Secretary-Treasurer. Ballots to be valid must be enclosed in an envelope carrying on the outside the written signature of the member submitting the ballot, and must be received by the Secretary-Treasurer at his officially recognized address not later than ten days prior to the Annual Meeting. Only ballots received from members in good standing as of a date ten days prior to the Annual Meeting shall be valid. . . .**

FOR PRESIDENT

R. D. WYCKOFF	☐
C. A. HEILAND	☐
----------	☐

FOR VICE-PRESIDENT

JAMES B. MACELWANE, S. J.	☐
W. M. RUST, JR.	☐
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FOR SECRETARY-TREASURER

HART BROWN	☐
JOHN A. GILLIN	☐
----------	☐

* Joseph A. Sharpe elected Editor 1942–1945.

After voting, place in accompanying official envelope, which should then be signed and mailed to the

SECRETARY-TREASURER,
T. I. HARKINS,
901 Esperson Bldg.,
Houston, Texas

NOMINEES FOR 1943–1944 EXECUTIVE COMMITTEE

The following brief biographical sketches are presented in an attempt to acquaint members with nominees appearing on the official ballot which was mailed out December 15, 1942.

FOR PRESIDENT

R. D. WYCKOFF received his B.S. in E.E. at Michigan State College in 1920. After a short period as M.E. in the plant engineering department of the Ford Motor Company, one and one-half years on the E.E. staff at Michigan State College, and two years in general electrical engineering work at Lansing, Michigan, he joined the staff of the U. S. Bureau of Standards, Electrical Instrument Section, remaining for a three-year

R. D. WYCKOFF

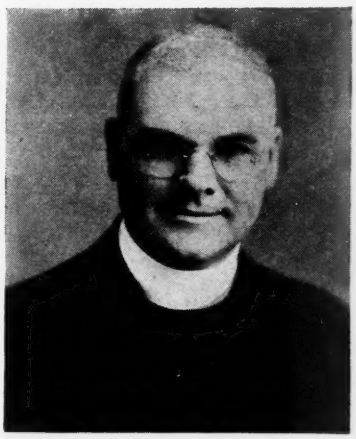
C. A. HEILAND

period. In 1926 Mr. Wyckoff entered the geophysical field with the Marland Oil Company in Oklahoma, and in 1929 joined the staff of the Gulf Research and Development Company, primarily to continue development of pendulum apparatus, and later in charge of the Physics Division. During the latter period he was associated with the development of gravimeters and general production research. In 1936 he again entered the Geophysics Division and from 1936 through 1939 was District Supervisor in the Gulf Research and Development Company's Houston office. Since that time he has been a member of the geophysical staff at Pittsburgh. He is a Fellow in the American Physical Society and a member of the Institute of Radio Engineers, the American Institute of Mining and Metallurgical Engineers, the American Petroleum Institute, the American Geophysical Union, and the Society of Exploration Geophysicists. He served as Editor of the Society from 1939 to 1942, in which year he was elected Vice-President.

C. A. HEILAND received his Sc.D. degree from the University of Hamburg in 1923. He engaged in magnetometer work for the State of Hamburg in 1921, and conducted

torsion balance surveys for the Raky Drilling Company while at the University of Heidelberg from 1922 to 1923. He resigned from this company in 1924 to take charge of the Geophysical Department of the Askania Werke in Berlin. In the following year he came to the United States as the representative of the same company, establishing offices in Houston, Texas. Late in 1926 he joined the faculty of the Colorado School of Mines and organized the Department of Geophysics, continuing as head of this department to date. Since 1934 he has been president of the Heiland Research Corporation in Denver, Colorado. Dr. Heiland has contributed more than a hundred articles on geophysics to various technical journals and is the author of *Geophysical Exploration*, published in 1940. At present most of his time is devoted to design and production problems for the Army, Navy, and Lend-Lease Departments, and to strategic mineral investigations. He is now serving as chairman of the Geophysics Committee of the American Institute of Mining and Metallurgical Engineers, and is also a member of the American Geophysical Union, the Seismological Society of America, the American Association of Petroleum Geologists, and the Society of Exploration Geophysicists.

FOR VICE-PRESIDENT



J. B. MACELWANE, S.J.

W. M. RUST, JR.

JAMES B. MACELWANE, S.J., received his A.B. degree in 1910, his A.M. in 1911, and his M.S. in 1912 from St. Louis University. In 1923 he received the degree of Ph.D. in physics from the University of California. He held an assistantship in meteorology and seismology at Saint Louis University 1910–1912 and an instructorship in physics 1912–1913. He was appointed Assistant Professor of Physics at the same university 1913–1915 and 1918–1919. He acted as assistant in seismology at the University of California in Berkeley 1921–1923 and was appointed Assistant Professor of Geology 1923–1925, being placed in charge of the seismograph stations and, further, organizing graduate studies in seismology. In 1925 he was called to Saint Louis University as Professor of Geophysics to organize the Department of Geophysics. He was appointed its Director and has remained in that position. Father Macelwane is a fellow of the Geo-

logical Society of America; a life member and Past President of the Seismological Society of America; a fellow of the American Association for the Advancement of Science, serving as Chairman of Section E, Geology and Geography, in 1934; a member of the American Geophysical Union, serving as President of the Section of Seismology 1938–1941; a member of the American Physical Society, the American Meteorological Society, the American Geographical Society, the American Institute of Mining and Metallurgical Engineers, and the Society of Exploration Geophysicists. He is a Past President of the Missouri Academy of Science and also of the Academy of Science of Saint Louis. He was joint author with J. I. Shannon of *A Loose-Leaf Manual of Laboratory Experiments in Physics* (Saint Louis University); joint author with F. W. Sohon. of *Introduction to Theoretical Seismology* and wrote Volume I, *Geodynamics* (John Wiley and Sons); editor and part author of *Seismology* (Bulletin 90 of the National Research Council); and part author of *Internal Constitution of the Earth* (McGraw-Hill), edited by B. Gutenberg.

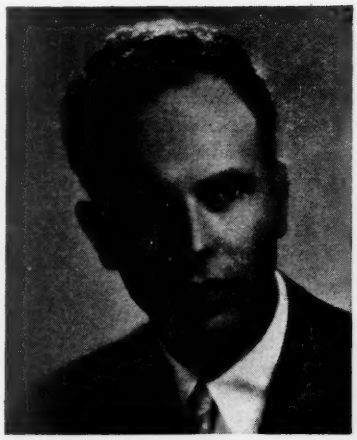
W. M. RUST, JR., received his A.B. in 1928 from Rice Institute and served as a fellow there from 1928 until 1931, in which year he received his Ph.D. in Mathematics and Geophysics. He served as a Mathematics Instructor at Rice Institute 1931–1932; International exchange fellow in Germany 1932–1933; and Instructor and tutor in mathematics at Harvard University 1933–1934. In 1934 he joined the staff of the Geophysics Research Division of the Humble Oil and Refining Company as a Research Geophysicist, engaging in research on seismograph prospecting and electrical well-logging, including the design of various electronic and mechanical equipment. He continued in this capacity until February, 1938, when he was made Division Head. He is a member of the American Mathematical Society, the American Physical Society, the American Geophysical Union, the American Association for the Advancement of Science, the American Institute of Mining and Metallurgical Engineers, the Seismological Society of America, and the Society of Exploration Geophysicists. He served as Secretary-Treasurer of the last-named Society 1941–1942.

FOR SECRETARY-TREASURER

HART BROWN received his B.S. in Electrical Engineering from Rice Institute in 1925. Upon graduation he joined the Test Department of General Electric Company in Schenectady, New York. From 1927 through 1930 he worked on development of electrical methods for oil prospecting with the General Exploration Company. In 1931 he enrolled in the graduate school of Washington University in Saint Louis and received his M.S. in Physics in 1933. From 1934 through 1936 he was associated with the Coastal Oil Finding Company, at that time contracting torsion balance services. Concurrently he was developing a gravity-meter. In 1939 he organized the Brown Geophysical Company to contract gravity-meter services using the completed instrument. He is a member of the American Institute of Mining and Metallurgical Engineers, the American Association of Petroleum Geologists, and the Society of Exploration Geophysicists.

JOHN A. GILLIN received his A.B. degree in 1930 and his M.A. degree in Physics in 1933 from the University of Oklahoma. Since graduation he has been associated with Geophysical Service, Inc., Champlin Refining Company, Western Geophysical Company, and National Geophysical Company. He designed and constructed the first seismograph recording apparatus used by the Champlin Refining Company. In 1936 he joined the National Geophysical Company as vice-president and field supervisor, serving in these capacities until November 1940, when he was elected president. In

HART BROWN



JOHN A. GILLIN

January, 1941, when the company was formed into a partnership, he became senior partner and manager. He is a member of the Dallas Geological Society and the Society of Exploration Geophysicists.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the Secretary within thirty days. (Names of sponsors are placed beneath the name of each nominee.)

ACTIVE

Edward Day Alcock
J. H. Pernell, Charles C. Williams, C. G. McBurney

Ellsworth Eugene Conant
C. Hewitt Dix, Lawrence K. Morris, Cecil E. Reel

John Warlaumont Daly
Clyde H. Wilson, Herbert Hoover, Jr., W. Hafner

Julian Frank Evans
Joseph A. Sharpe, Vincent Emanuel, Daniel Silverman

Robert Stanley Finn
Stanley W. Wilcox, F. B. Leedy, J. E. Hawkins

Albert Alfred Fitch
Stanley W. Wilcox, R. F. Aldredge, F. B. Leedy

Noel Frost
Stanley W. Wilcox, F. B. Leedy, J. E. Hawkins

Walter Emil Heinrichs, Jr.
Stanley W. Wilcox, F. B. Leedy, J. E. Hawkins

Arthur Maxwell House
Stanley W. Wilcox, F. B. Leedy, J. E. Hawkins
Joe Bailey Hudson
Dave P. Carlton, Henry V. Goss, J. E. LaRue
Bill Bassett Hunkapiller
F. Goldstone, M. O. Gibson, Claude Wendell Horton
James Franklin Johnson
E. J. Handley, H. R. Prescott, L. F. Athy
James Rudolph Johnson
John L. Bible, Garvin L. Taylor, R. Clare Coffin
James Linden Kezeler
Stanley W. Wilcox, F. B. Leedy, J. E. Hawkins
Beverly Wichterich Koeppel
Stanley W. Wilcox, F. B. Leedy, J. E. Hawkins
Robert Scott Lamon
T. J. Etherington, Ygnacio Bonillas, R. G. Elms
Carl Leonard Larson, Jr.
Joseph A. Sharpe, R. Clare Coffin, Garvin L. Taylor
Nash Hugh Miller
Hugh C. Schaeffer, C. Hewitt Dix, Cecil E. Reel
John Clement Mollere
Joseph A. Sharpe, Jack R. Cooper, Vincent Emanuel
William Howard Myers
Cecil E. Reel, Lawrence K. Morris, C. Hewitt Dix
Pernell Justice Moore
Stanley W. Wilcox, F. B. Leedy, J. E. Hawkins
Chaim Leib Pekeris
Joseph A. Sharpe, L. B. Slichter, N. A. Haskell
Sidney William Schoellhorn
Stanley W. Wilcox, H. C. Becker, J. E. Hawkins
Lorenz Ira Shock
J. H. Pernell, Charles C. Williams, C. G. McBurney
Warren Howard Smith
Roy L. Lay, J. H. Deming, Louis A. Scholl, Jr.
Kirby Jay Warren
G. C. Howard, R. W. Gemmer, George E. Wagoner
Russell Albert Weingartner
Joseph A. Sharpe, R. Clare Coffin, Garvin L. Taylor

ASSOCIATE

Pertev Ibrahim Bediz
R. Maurice Tripp, Dart Wantland, C. A. Heiland
Donald Charles Bowman
Stanley W. Wilcox, F. B. Leedy, J. E. Hawkins
Herbert Henry Campbell
Stanley W. Wilcox, F. B. Leedy, J. E. Hawkins
Ruff King Finley
Stanley W. Wilcox, H. C. Becker, J. E. Hawkins

Jack Louis Friendly
Stanley W. Wilcox, F. B. Leedy, J. E. Hawkins
James Haydon Ransom
J. Frank Rollins, M. C. Kelsey, M. P. Jones
Joe Hiram Moore
(Article III-D-1 of the Constitution)
Henry Francis Wise
Norman J. Christie, Lawrence K. Morris, C. Hewitt Dix
John Robert Woolson
Cecil E. Reel, C. Hewitt Dix, John J. Rupnik

STUDENT

David Coolbaugh
Dart Wantland

PERSONAL ITEMS

WORTH B. HURT, formerly with the Magnolia Petroleum Company, is now a Seismic Party Chief with the National Geophysical Company, Tower Petroleum Building, Dallas, Texas.

Word has been received that B. DE BLANK, stationed in the Dutch East Indies at the outbreak of the war, has been interned by the Japanese.

C. E. WILLIAMS was erroneously listed in the last membership list as an Assistant Recorder. He has advised the Society that he has been serving as a Recorder with the Texas Company since October, 1938.

H. M. HORTON has transferred his office from Evansville, Indiana, to the American Bank Building, Mt. Carmel, Illinois.

In addition to acting as President of Techni-Counsel Ltd., which organization is engaged in magnetometer surveys near Val d'or, TH. KOULOMZINE is serving as Mine Manager for Central Cadillac Mines Ltd., Cadillac, P. Q., Canada.

Word has been received of the death in a Nazi prison in Paris, under suspicious circumstances, of Dr. FERNAND HOLWECK. Dr. Holweck, who is known to geophysicists as co-developer of the Holweck-Lejay gravimetric pendulum, worked on ultrasonic means of submarine detection during the first World War, and was again actively engaged in military inventions from the start of the second World War until the occupation of France.

ETHEL WARD MCLEMORE has accepted employment as a Computer with the United Geophysical Company, 1255 East Green Street, Pasadena, California.

FIELDING L. MITCHELL, formerly with the International Petroleum Company in Ecuador, is serving as a physicist with the U. S. Navy Department, Magnetic Survey Range, San Rafael, California.

B. G. HUBNER, Party Chief with the National Geophysical Company, is now located at P. O. Box 535, Jacksboro, Texas.

NATHAN C. DAVIES, Consulting Geologist and Engineer, has moved his office from Fairfield, Illinois, to 1102 Oakland Avenue, Mt. Vernon, Illinois.

ROBERT BERESFORD, formerly with the Mott-Smith Corporation in Egypt, is serving as an Assistant Electrical Engineer in the Naval Ordnance Laboratory, Washington, D. C. His mailing address is 2009 Branch Avenue, S.E.

JAMES E. DORRIS has returned from foreign duty and may be addressed c/o Seismograph Service Corporation, Kennedy Building, Tulsa, Oklahoma.

FLOYD WILLIS, JR., is serving as an Engineer in the Naval Ordnance Laboratory. His mailing address is 800 L Street, S.E., Washington, D. C.

ROY A. HILL, formerly with the Stanolind Oil and Gas Company, has been commissioned a First Lieutenant in the U. S. Army Signal Corps and is in overseas service.

Mail should be sent him through his father, C. L. Hill, 3421 Walnut Street, Huntington Park, California.

NORMAN A. HASKELL should be addressed c/o John F. Golden, 218 Vine Street, Everett, Massachusetts.

J. BYRON JONES has returned from Venezuela and may be reached at 405 Front Street, Northumberland, Pennsylvania.

DAVID M. WEBER has transferred to foreign service and should be addressed c/o Mene Grande Oil Co., C. A., Aptdo. 45, Barcelona, Venezuela.

J. C. HEGGBLOM, of the Western Gulf Oil Co., has moved from Modesto to Sacramento, California, where his mailing address is P. O. Box 983.

RALPH C. LORING, formerly with the United Geophysical Company, is now serving as an Associate Physicist, on civilian duty with the U. S. Army Signal Corps. His home address is 703 4th Avenue, Asbury Park, New Jersey.

RICHARD L. DOAN has been granted a leave of absence by the Phillips Petroleum Company to assume administrative duties in the Metallurgical Laboratory, Eckhart Hall, University of Chicago, Chicago, Illinois.

MERLE C. BOWSKY, formerly with Lane-Wells, has been commissioned a Lieutenant in the U. S. Army Signal Corps. He should be addressed at the Santander Hotel, Asbury Park, New Jersey.

W. W. WARING should be addressed c/o Mr. Wm. F. Hill, 6670 Kinsman Road, Pittsburgh, Pennsylvania.

ROBERT L. GEYER, of the Shell Oil Co., Inc., has been transferred from Graham to Olney, Texas, with the mailing address P. O. Box 865.

FRANCIS H. CADY should be addressed c/o Carter Oil Company, P. O. Box 801, Tulsa, Oklahoma.

WILLIAM R. CAMPBELL, formerly with the Stanolind Oil and Gas Company, has been commissioned a Lieutenant and is serving with the 780th M. P. Bn., Ft. Huachuca, Arizona.

G. C. HOWARD, of the Carter Oil Co., has notified the Society of his new address: P. O. Box 294, Canton, Mississippi.

JOHN W. FLUDE is serving as a Physicist in the U. S. Navy Bureau of Ordnance. His address is 561 Shackamaxon, Westfield, New Jersey.

A. B. WINTER, of Lane-Wells, has been transferred from Oklahoma City to P. O. Box 1407, Houston, Texas.

O. C. OLSON has completed a six months' contract with the U. S. Engineers as an Associate Engineer (Civil) and has returned to Texas to accept a position as Petroleum Engineer with the Texas Railroad Commission, Oil and Gas Division, Pampa District, Pampa, Texas.

LOUIS B. SLICHTER is serving the National Defense Research Committee as a Section Member of Section C-4. His new address is 345 S. Michigan Avenue, Pasadena, California.

H. W. STRALEY, III, has left the Eastern Exploration Co., Inc., to accept a position as Analyst for the Board of Economic Warfare. His mailing address is P. O. Box 5532, Friendship Station, D. C.

LOUIS C. PAKISER, JR., Junior Geophysicist with the Carter Oil Company, is located at P. O. Box 622, Norman, Oklahoma.

JAMES J. ROARK, Operator with the Carter Oil Company, has been transferred from Yellville, Arkansas, to Canton, Mississippi.

ARNOLD J. F. SIEGERT, formerly with the National Geophysical Company, is now doing research in the interpretation of gravity and magnetic observations for Stanolind Oil and Gas Co., P. O. Box 591, Tulsa, Oklahoma.

MORRIS MUSKAT, on leave from the Gulf Research and Development Company, is serving as Section Head in the Naval Ordnance Laboratory, U. S. Navy Yard, Washington, D. C.

E. MAXWELL, Staff Member in the Radiation Laboratory, Massachusetts Institute of Technology, is located at 161 Cypress Street, Brookline, Massachusetts.

W. A. MESZAROS, Geophysicist with the Gulf Research and Development Company, has returned to the States from foreign duty and may be addressed at 347 Johnston Avenue, Pittsburgh, Pennsylvania.

A. B. PENNEY has returned safely from Sumatra, where he was on duty at the outbreak of war, and is serving in an Engineer Training Battalion. Correspondence should be sent him at 1405 19th Street, Lubbock, Texas.

BOOTH B. STRANGE, of the Western Geophysical Co., has moved from West Point to Laurel, Mississippi.

DAVID S. MUZZEY, JR., has accepted a position as Physicist with the Naval Ordnance Laboratory. His home address is 2100 34th Street, S.E., Washington, D. C.

HOMER C. MOORE has left the Texas Company to accept a position as Chief of the Exploration and Geological Department for the Mid-Continent Petroleum Corporation, Tulsa, Oklahoma. He may be addressed at 3030 S. Wheeling, Tulsa.

MAURICE SKLAR, of the Shell Oil Co., Inc., is now located at P. O. Box 31, Vandalia, Illinois.

VINCENT J. MERCIER, of the Lane-Wells Company, has moved from Oklahoma City to 1038 Coolidge Street, Seminole, Oklahoma.

ROBERT BARLING, of the Miller Geophysical Company, is now located at the Hotel Del Mar, Woodland, California.

ROBERT W. ADAMS, of the Richfield Oil Corporation, has been commissioned an Ensign, A-V(P), in the U. S. Naval Reserve. Correspondence addressed to him at P. O. Box 664, Reseda, California, will reach him in due order.

F. L. JOHNSON, formerly with the Sun Oil Company, is serving as a Physicist in the Naval Ordnance Laboratory, U. S. Navy Yard, Washington, D. C. His home address is 4200 28th Street, Apt. 31, Mt. Rainier, Maryland.

C. Y. FU has left the Colorado School of Mines to become a Teaching Fellow in Geophysics, Division of Geological Sciences, California Institute of Technology, Pasadena, California.

FRANCIS A. HALE, Party Chief with Geophysical Service, Inc., should be addressed at P. O. Box 617, Bakersfield, California.

E. I. HEAD, of the Gulf Research and Development Company, has moved from Ft. Stockton to Three Rivers, Texas, with the postal address P. O. Box 122.

B. F. HOWELL, JR., formerly a Teaching Fellow at the California Institute of Technology, has accepted a position as Technical Assistant in the Division of War Research, University of California, Room 1, 701 S. 7th Street, San Diego, California.

Kennedy R. Marble, Junior Geophysicist with the Carter Oil Company, is located in Stockton, Kansas, with the mailing address P. O. Box 836.

MARION H. GILMORE, formerly with the U. S. Coast and Geodetic Survey, has been commissioned a Lieutenant in the U. S. Naval Reserve. He is at present working with the U. S. Navy Department Bureau of Ordnance and should be addressed at his home: P. O. Box 233, Mar Vista, California.

Major ROBERT W. JACKSON, of the U. S. Army Signal Corps, who was stationed in Manila upon the outbreak of war, has been reported "missing in action" since last May.

Major DREXLER DANA, now on active duty overseas, may be reached through the Engineer Forces, A. P. O. 887, c/o Postmaster, New York, N. Y.

T. F. JOHNSTON, formerly stationed in the U. S. Navy Radio and Sound Laboratory in San Diego, is now serving as Research Associate in the Division of War Research of the University of California, and may be addressed at P. O. Box 2471, San Diego, California.

FORREST F. LAMBRECHT has been commissioned a First Lieutenant in the Corps of Engineers upon completion of training at the Officer Candidate School in Ft. Belvoir, Virginia. He is stationed at Hq. 7th E. T. Group, Fort Leonard Wood, Missouri.

HARVEY CASH, JR., formerly Party Chief for the Texas Company, has been commissioned a Captain in the U. S. Army Signal Corps. His home address is 2717 South Adams Street, Arlington, Virginia, and he is stationed in Washington, D. C.

Captain JOHN M. GOLDEN, formerly with Elflex, is stationed at Camp Hq., Camp Bowie, Texas.

JOHN G. COOKE, JR., has been advanced to the rank of Captain, and is stationed at Tuskegee Army Flying School, Tuskegee, Alabama.

C. E. VAN ORSTRAND, Geophysicist (Retired) with the U. S. Geological Survey, is completing a report on "Deep Earth Temperatures of the Globe" without compensation from the government.

JOHN M. NASH has been advanced to the rank of Major, and is serving as Commanding Officer of the 926th Signal Bn., A. S. C., Army Air Base, Birmingham, Alabama.

A. E. MCKAY has been advanced to the rank of Captain, and is stationed at the Army Air Forces School of Applied Tactics, Orlando, Florida.

ARCTIC, DESERT AND TROPIC INFORMATION CENTER, U. S. ARMY AIR FORCES

FIRST LIEUTENANT CALVIN C. FLINT of the U. S. Army Air Corps has notified the Society of the organization of the Arctic, Desert and Tropic Information Center, with headquarters at Eglin Field, Florida. Society members now in the Army who have had appreciable experience in desert and tropic regions and who would be interested in serving in this branch are requested to write the Director of the newly-organized Information Center at Eglin Field. Civilian members with similar experience who are interested in securing a commission in this branch of the service are also invited to forward their inquiries. The need is of the utmost urgency, and all qualified Society members are urged to communicate promptly with the Director, Arctic, Desert and Tropic Information Center, Eglin Field, Florida.

THE NAVAL ORDNANCE LABORATORY, located in the Navy Yard, Washington, D. C., is a research and development agency of the Bureau of Ordnance, concerned with the design of new types of naval mines, depth charges, aerial bombs and other ordnance equipment, including measures for the protection of ships against mines.

This laboratory is urgently in need of additional technical personnel. Physicists and electrical engineers with electronics experience are required. The laboratory also needs mechanical engineers familiar with the design of small mechanical movements or mechanisms. Several openings are available in technical report writing and editing.

MEMBERS OF THE SOCIETY OF EXPLORATION GEOPHYSICISTS SERVING IN THE ARMED FORCES, OR ENGAGED IN WORK DIRECTLY RELATED TO THE PROSECUTION OF THE WAR

The list below gives the names and mailing addresses of those members of the Society who are serving in the armed forces, or who are engaged in work directly related to the prosecution of the war. The list is admittedly incomplete, and any omissions or incorrect listings should be brought to the attention of the Business Manager, Mr. J. F. Gallie, Box 1925, Washington, D. C.

Although every member of the Society of Exploration Geophysicists is engaged in a vital and essential activity, i.e., assisting in the discovery of petroleum, it is of interest to note that, in addition, about 15% of the total membership is even more directly concerned with the prosecution of the war. Of this group, about one half are in military service (many in technical branches), and one half are engaged in research on and the development of military devices.

Adams, Robert W. (Ensign, A-V(P), U.S.N.R.), P. O. Box 664, Reseda, Calif.

Arick, M. B. (Lieutenant, Army Air Corps), 1010 W. Indiana St., Midland, Tex.

Barnett, G. W. T., No. 10 A. W. Co., Force X, "C" Base Post Office, Basrah, Iraq

Bates, Charles C. (A/C, Meteorology, U. S. Army Air Corps), 10912½ Wellworth, Los Angeles, Calif.

Batson, James B. (1st Lt., O.P.N. Co.), 53rd Signal Bn., Camp Bowie, Tex.

Bench, B. M. (Major, Hq. XI Eng. Corps), c/o Mr. V. G. Bench, 2305 E. 70th St., Chicago, Ill.

Benke, M. L. (1st Lt., U. S. Army Signal Corps), 802 Waverly Ave., San Antonio, Tex.

Bowsky, Merle C. (1st Lt., U. S. Army Signal Corps), Santander Hotel, Asbury Park, N. J.

Brooks, James A., Jr. (Lt., U.S.N.R.), 3003 34th St., N.W., Washington, D. C.

Bryan, Carl L. (Lt., U.S.N.R.), 2405 Isabella Ave., Houston, Tex.

Campbell, William R. (2nd Lt., Supply Officer and Duty Officer, Co. A, 780th M. P. Bn., U. S. Army), 780th M. P. Bn., Ft. Huachuca, Ariz.

Cash, Harvey, Jr. (Capt., U. S. Army Signal Corps), 2717 S. Adams St., Arlington, Va.

Lt. Joseph H. Church (Lt., U.S.N.R.), USS Milwaukee, c/o Postmaster, New York, N. Y.

Cooke, John G., Jr. (Capt., Commandant of Cadets, U. S. Army Air Corps), Tuskegee Army Flying School, Tuskegee, Ala.

Cox, Charles B. (Lt., U. S. Armored Force), 202 Irving St., Denver, Colo.

Cox, Harris (Lt., U. S. Navy), U. S. Navy Dept., Washington, D. C.

Crowell, J. H. (Lt., U. S. Navy, Bureau of Ships), 3416 Ella Lee Lane, Houston, Tex.

Dana, Drexler (Major, Corps of Engineers, U. S. Army), Engineer Forces, A. P. O. 887, c/o Postmaster, New York, N. Y.

Dickey, Calvin A. L. (Major, 8th F. A. Obsn. Bn., U. S. Army), 8th F. A. Obsn. Bn., Camp Blanding, Fla.

Doolittle, Russell C. (Ensign, A-V(S), Photographic Interpretation, U.S.N.R.), c/o Mr. F. W. Doolittle, 79 Brompton Rd., Garden City, L. I., N. Y.

Egan, D. G. (1st Lt., U. S. Army Signal Corps), P.O. Box 366, Crowley, La.

Elam, Daniel F. (2nd Lt., U. S. Army Air Corps), 808 N. 15th St., Duncan, Okla.

Ervin, Lynn D. (Capt., U. S. Marine Corps), U.S.M.C., P. O. Box D, Marine Corps Base, Guantanamo Bay, Cuba.

Faris, J. P., Jr. (1st Lt., Corps of Engineers, U. S. Army), B.O.Q., Randolph Field, Tex.

Fetzer, E. L. (1st Lt., 319 C. A., Bar. Bln. Bn.), c/o Mrs. E. L. Fetzer, 401 LaSalle St., Navasota, Tex.

Fleishman, Sam (Capt., U. S. Army Air Corps), Pendleton Field, Pendleton, Ore.

Gilmore, Marion H. (Lt., U.S.N.R., Bureau of Ordnance), P. O. Box 233, Mar Vista, Calif.

Golden, John M. (Capt., Operations and Training Officer, U. S. Army), Camp Hq., Camp Bowie, Tex.

Hill, Roy A. (1st Lt., U. S. Army Signal Corps), 3421 Walnut St., Huntington Park, Calif.

Honnell, P. M. (Major, U. S. Army Signal Corps), Dept. of Chemistry and Electricity, U. S. Military Academy, West Point, N. Y.

Hostetler, G. W. (Capt., U. S. Army Signal Corps, Tank Automotive Center, Detroit, Mich.), 1403 S. Main St., Goshen, Ind.

Imle, Harry R. (Capt., U. S. Army Field Artillery), Staff and Faculty, F. A. S., Communication Depot, Ft. Sill, Okla.

Jackson, Robert W. (Major, U. S. Army Signal Corps), 4907 Tremont, Dallas, Tex. (*reported missing in action*)

Johnson, G. R. (Sub-Lt., Royal Canadian Navy Volunteer Reserves), Canadian Fleet Mail Office, 10 Haymarket, London, England.

Kaiser, George B. (Lt. Col., U. S. Army Signal Corps, Hq. Army Air Forces), 432 20th St., N.W., Washington, D. C.

Kearby, J. G. (Capt., Unit Chief, Oxygen and High Altitude Laboratory, U. S. Army Air Corps), Experimental Eng. Section, Wright Field, Dayton, Ohio

Kennedy, Kenneth K. (1st Lt., U. S. Army), A.S.N. 0-888012, Base Signal Office, A. P. O. 922, c/o Postmaster, San Francisco, Calif.

Klipsch, Paul W. (Capt., Ord. Dept., U. S. Army), Southwestern Proving Ground, Hope, Ark.

Kunkel, T. L. (1st Lt., U. S. Army Coast Artillery), 1609 Taylor St., Wichita Falls, Tex.

Lambert, G. D. (Capt., U. S. Army), 2nd Bn., 63rd C. A., Seattle, Wash.

Lambrecht, Forrest F. (1st Lt., Corps of Engineers, U. S. Army), Hq. 7th E. T. Group, Ft. Leonard Wood, Mo.

Lipson, Edward (Major, U. S. Army Signal Corps), 2900 Argyle Dr., Monticello Park, Alexandria, Va.

Long, John V. (Capt., U. S. Army), 4120 5th Ave., San Diego, Calif.

Lynn, Ralph D. (Lt., U. S. Army), 7th F. A. Obsn. Bn., Camp Shelby, Miss.

Maliphant, H. C. (Lt., School of Artillery Bldg., S. Head, Sydney, Australia), c/o Shell Oil Co. of Australia, Shell House, Sydney, N. S. W., Australia.

Martin, Walter E. (Sgt., U. S. Army Air Force Weather Service), Hempstead, N. Y.

Mathews, John W. (Capt., U. S. Army Corps of Engineers), 530 Hillcrest Dr., Bakersfield, Calif.

Maxwell, Joseph M. (Capt., U. S. Army Corps of Engineers), Staff and Faculty, Engineer School, Ft. Belvoir, Va.

McCready, H. J., Jr. (U-3, U.S.N.R.), 4923 Knox Court, Denver, Colo.

McKay, A. E. (Capt., U. S. Army Air Corps), Army Air Forces School of Applied Tactics, Orlando, Fla.

McMullin, E. F. (1st Lt., U. S. Army Signal Corps), 2324 N.E. 25th, Oklahoma City, Okla.

Morgan, Chas. Gill (Lt. Col., U. S. Army Air Corps), Apt. 196, Arlington Village, Arlington, Va.

Mortlock, Frank O. (U. S. Navy), c/o F. E. Mortlock, 601 Clyde St., Pittsburgh, Pa.
Nahas, J. N. (Capt., U. S. Army Signal Corps), 1210 Ashley Ave., Beaumont, Tex.
Nash, Cleve C., Jr. (1st Lt., U. S. Army Signal Corps), RCM Div., Aircraft Radio Lab., Wright Field, Dayton, Ohio
Nash, John M. (Major, Commanding Officer, U. S. Army Signal Corps), 926 Sig. Bn., A.S.C., Army Air Base, Birmingham, Ala.
Nisle, Robert G. (Ensign, Radio Eng., U.S.N.R.), 601 Bomar, Houston, Tex.
Paterson, R. G. (Lt., S.B., Royal Canadian Naval Volunteer Reserve), c/o Naval Officer in Charge, Vancouver, B. C., Canada
Penney, A. B. (Pvt., U. S. Army, Eng. Tng. Bn.), 1405 19th St., Lubbock, Tex.
Perkins, Beauregard, Jr. (Lt. Cmdr., U.S.N.R.), Navy Dept., Bureau of Ordnance, Washington, D. C.
Prade, Nat H. (Ensign, U.S.N.R.), Instructor, Naval Mine Warfare School, Yorktown, Va.
Pranglin, John A. (Capt., Commanding Officer, Co. B, 833 Eng. Bn.), c/o Judge John L. Pranglin, Pearsall, Tex.
Saville, W. G. (Lt. Col., U. S. Army Corps of Engineers), 1348 Esperson Bldg., Houston, Tex.
Schoellhorn, Henry, III (Sgt., U. S. Army Signal Corps), Det. 7th Signal Service Co., Ft. Ringgold, Tex.
Shafer, R. E. (Lt., U. S. Army Air Corps), Ellington Field, Tex.
Shepherd, C. K. (1st Lt., U. S. Army), 4005 Hanover, Dallas, Tex.
Smitherman, Lynn A. (2nd Lt., U. S. Army Signal Corps), P. O. Box 67, Athens, Tex.
Steele, W. E., Jr. (Capt., U. S. Army Signal Corps), 4119 W St., N.W., Washington, D. C.
Stoneham, S. C. (Lt., AV/RS, U.S.N.R.), 2407 Jefferson Park Ave., Charlottesville, Va.
Uhrig, L. F. (Capt., U. S. Army, Armored Force Ordnance), c/o Maintenance Bn., 5th A. D., Camp Cooke, Lompoc, Calif.
Weisbrich, R. A. (Lt., Hq. R.O.T.C.), Univ. of Minnesota, Minneapolis.

ENGAGED IN WORK DIRECTLY RELATED TO THE PROSECUTION OF THE WAR

Antes, Leland L. (Engineering Science and Management Defense Training, U. S. Office of Education, Univ. of Texas), 2405 Red River, Austin, Tex.
Arthur, Marion A. (Engineer, Office of Scientific Res. and Dev.), Dept. of Terrestrial Magnetism, Carnegie Inst. of Washington, Washington, D. C.
Beresford, Robert (Asst. Elec. Engineer, Naval Ord. Lab.), 2009 Branch Ave., S.E., Washington, D. C.
Brown, Leon D., Jr. (Engineer, Consolidated Aircraft Corp.), 1708 Madison Ave., San Diego, Calif.
Carson, J. P. (Mech. Engineer, Special Engineering Div.), P. O. Box 109, Diablo Heights, Canal Zone
Cronin, Eugene J. (Elec. Engineer, Federal Bureau of Investigation), 2326 39th St., N.W., Washington, D. C.
De Golyer, E. L. (Asst. Deputy Coordinator), Office of Petroleum Coordinator, Washington, D. C.
Doan, Richard L. (Administrative Officer), Metallurgical Lab., Eckhart Hall, Univ. of Chicago, Chicago, Ill.
Dobrin, Milton B. (Physicist, Naval Ord. Lab.), 1404 Tuckerman St., N.W., Washington, D. C.
Dodd, Lavon C. (Elec. Layout Draftsman, Lockheed Aircraft Corp., Burbank, Calif.), 1324 Irving, Glendale, Calif.

Evinger, H. H. (Physicist, Naval Ord. Lab.), 501 Oakwood St., S.E., Washington, D. C.

Ewing, Maurice (Assoc. in Submarine Geology), Woods Hole Oceanographic Inst., Woods Hole, Mass.

Flude, J. W. (Physicist, U. S. Navy Bureau of Ordnance), 561 Shackamaxon Dr., Westfield, N. J.

Gallie, J. F. (Procurement Representative, Naval Ord. Lab.), P. O. Box 1925, Washington, D. C.

Garrett, George A. (Staff Member, Radiation Lab., M.I.T.), 81 Elm St., Belmont, Mass.

Gayman, W. H. (Structures Test Engineer, Vega Aircraft Corp.), 223 W. Ash St., Burbank, Calif.

Gould, Martin J. (Radio Engineer, U. S. Navy Dept. Bureau of Ships), 4607 Connecticut Ave., N. W., Apt. 103, Washington, D. C.

Haskell, Norman A. (Staff Member, Div. of Nat'l Defense Res., Columbia Univ.), c/o John F. Golden, 218 Vine St., Everett, Mass.

Hedeman, W. R., Jr. (Assoc. Elec. Engineer, U. S. Navy Dept.), 2017 37th St., S.E., Washington, D. C.

Heroy, William B. (Dir., Div. of Reserves, Office of Pet. Administrator for War), 311 Newport Ave., Washington, D. C.

Hersey, J. B. (Physicist, Naval Ord. Lab.), 1517 R St., N.W., Washington, D. C.

Hoffman, Malvin G. (Office of Pet. Coordinator), 3821 W St., S.E., Fairfax Village, Washington, D. C.

Howell, B. F., Jr. (Tech. Asst., Div. of War Res., Univ. of California), Rm. 1, 701 S. 7th St., San Diego, Calif.

Howell, Lynn G. (Physicist), Applied Physics Lab., Johns Hopkins Univ., 8621 Georgia Ave., Silver Spring, Md.

Hughes, Darrell S. (Physicist), Naval Ord. Lab., U. S. Navy Yard, Washington, D. C.

Jaques, Alvin T. (Asst. Physicist, Naval Ord. Lab.), 601 Yuma St., S.E., Washington, D. C.

Johnson, F. L. (Physicist, Naval Ord. Lab.), 4200 28th St., Apt. 3, Mt. Rainier, Md.

Johnston, T. F. (Res. Assoc., Univ. of California Div. of War Res.), P. O. Box 2471, San Diego, Calif.

Kendall, James M. (Engineer, Naval Ord. Lab.), 1102 45th Place, S.E., Washington, D. C.

Koenig, Palmer E. (Asst. Radio Engineer, Aircraft Radio Lab., U. S. War Dept.), 4302 N. Main, Dayton, Ohio

Lash, Charles C. (Contract Employee, Naval Ord. Lab.), 1643 Willowood Dr., Norfolk, Va.

Lehman, Frank F. (Swinerton, Hegeman, and McClure—U. S. Navy contract), P. O. Box 1413, Cristobal, Canal Zone

Lohse, John M. (Engineer, Johns Hopkins Univ. Applied Physics Lab.), 8718 Cameron St., Silver Spring, Md.

Loring, Ralph C. (Assoc. Physicist, U. S. Army Signal Corps), 703 Fourth Ave., Asbury Park, N. J.

MacAllister, C. T. (Chief Test Engineer, Houston Shipbuilding Corp.), 6326 Belmont, Houston, Tex.

Malamphy, Mark C. (Sr. Technologist, U. S. Bureau of Mines), P. O. Box 1714, Little Rock, Ark.

Martin, Sidney A., Jr. (Staff Member, Radiation Lab., M.I.T.), 14 Skahan Rd., Belmont, Mass.

Mason, Jack (Aerodynamist, Consolidated Aircraft Corp.), 3430 Elliott, San Diego, Calif.

Maxwell, E. (Staff Member, Radiation Lab., M.I.T.), 161 Cypress St., Brookline, Mass.

McGhee, George C. (Deputy Exec. Secretary for the U. S.), Combined Raw Materials Bd., Washington, D. C.

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STATEMENT OF OWNERSHIP, MANAGEMENT, CIRCULATION, ETC., REQUIRED BY THE ACTS OF CONGRESS OF AUGUST 24, 1912, AND MARCH 3, 1933

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City of Washington } ss.
District of Columbia }

Before me, a Notary Public in and for the State and county aforesaid, personally appeared J. F. Gallie, who, having been duly sworn according to law, deposes and says that he is the business manager of the GEOPHYSICS and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily paper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, as amended by the Act of March 3, 1933, embodied in section 537, Postal Laws and Regulations, printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are: Publisher, George Banta Publishing Company, Menasha, Wisconsin; Editor, Dr. Joseph A. Sharpe, P. O. Box 591, Tulsa, Oklahoma; Managing Editor, Dr. Joseph A. Sharpe, P. O. Box 591, Tulsa, Oklahoma; Business Manager, Mr. J. F. Gallie, P. O. Box 1925, Washington, D. C.

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J. F. GALLIE

Sworn to and subscribed before me this 12th day of October 1942.
[SEAL]

ESTHER V. KUHL

(My commission expires Feb. 1, 1947.)